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EVERYDAY SCIENCE

COMPILED BY

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EDWIN A. SCHELL, General Secretary.

A Hope of Inducing our Young People to take a Scientific Interest in their Everyday Surroundings, and to Cultivate Habits of Close Observation of Common Things, has led to the Compilation of these Pages.

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Introductory—Nature and Science

By PROFESSOR HUXLEY, F.R.S.

1. Sensations and Things.

ALL the time that we are awake we are learning by means of our *senses* something about the world in which we live and of which we form a part; we are constantly aware of feeling, or hearing, or smelling, and, unless we happen to be in the dark, of seeing; at intervals we taste. We call the information thus obtained *sensation*.

When we have any of these sensations we commonly say that we feel, or hear, or smell, or see, or taste something. A certain scent makes us say we smell onions; a certain flavor, that we taste apples; a certain sound, that we hear a carriage; a certain appearance before our eyes, that we see a tree; and we call that which we thus perceive by the aid of our senses a *thing*, or an *object*.

2. Causes and Effects.

Moreover, we say of all these things, or objects, that they are the *causes* of the sensations

in question, and that the sensations are the *effects* of these causes. For example, if we hear a certain sound, we say it is caused by a carriage going along the road, or that it is the effect or the consequence of a carriage passing along. If there is a strong smell of burning, we believe it to be the effect of something on fire, and look about anxiously for the cause of the smell. If we see a tree we believe that there is a thing, or object, which is the cause of that appearance in our field of view.

3. The Reason Why. Explanation.

In the case of the smell of burning, when we find on looking about that something actually is on fire, we say either that we have found out the cause of the smell, that we know the *reason why* we perceive that smell, or that we have *explained it*. So that to know the reason why of anything, or to explain it, is to know the cause of it. But that which is the cause of one thing is the effect of another. Thus, suppose we find some smoldering straw to be the cause of the smell of burning, we immediately ask what set it on fire, or what is the cause of its burning? Perhaps we find that a lighted lucifer match has been thrown into the straw, and then we say that the lighted match was the cause of the fire.

But a lucifer match would not be in that place

unless some person had put it there. That is to say, the presence of the lucifer match is an effect produced by somebody as cause. So we ask, Why did anyone put the match there? Was it done carelessly, or did the person who put it there intend to do so? And if so, what was his motive or the cause which led him to do such a thing? And what was the reason for his having such a motive? It is plain that there is no end to the questions, one arising out of the other, that might be asked in this fashion.

Thus we believe that everything is the effect of something which preceded it as its cause, and that this cause is the effect of something else, and so on through a chain of causes and effects which goes back so far as we choose to follow it. Anything is said to be explained as soon as we have discovered its cause, or the reason why it exists; the explanation is fuller if we can find out the cause of that cause, and the further we can trace the chain of causes and effects the more satisfactory is the explanation. But no explanation of anything can be complete, because human knowledge, at its best, goes but a very little way back toward the beginning of things.

4. Properties and Powers.

When a thing is found always to cause a particular effect we call that effect sometimes a *property*, sometimes a *power* of the thing. Thus

the odor of onions is said to be a property of onions because onions always cause that peculiar sensation of smell to arise when they are brought near the nose; lead is said to have the property of heaviness because it always causes us to have the feeling of weight when we handle it; a stream is said to have the power to turn a water wheel because it causes the water wheel to turn; and a venomous snake is said to have the power to kill a man because its bite may cause a man to die. Properties and powers then are certain effects caused by the things which are said to possess them.

5. Artificial and Natural Objects. Nature.

A great many of the things brought to our knowledge by our senses, such as houses and furniture, carriages and machines, are termed *artificial things* or *objects* because they have been shaped by the *art* of man; indeed they are generally said to be made by man. But a far greater number of things owe nothing to the hand of man, and would be just what they are if mankind did not exist: such as the sky and the clouds; the sun, moon, and stars; the sea, with its rocks and shingly or sandy shores; the hills and dales of the land, and all wild plants and animals. Things of this kind are termed *natural objects*, and to the whole of them we give the name of *Nature*.

6. Artificial Things are only Natural Things Shaped and Brought Together or Separated by Men.

Although this distinction between *nature* and *art*, between *natural* and *artificial* things, is very easily made and very convenient, it is needful to remember that, in the long run, we owe everything to nature; that even those artificial objects which we commonly say are made by men are only natural objects shaped and moved by men; and that, in the sense of *creating*—that is to say, of causing something to exist which did not exist in some other shape before—man can make nothing whatever. Moreover, we must recollect that what men do in the way of shaping and bringing together or separating natural objects is done in virtue of the powers which they themselves possess as natural objects.

Artificial things are, in fact, all produced by the action of that part of nature which we call mankind upon the rest.

We talk of "making" a box—and rightly enough, if we mean only that we have shaped the pieces of wood and nailed them together; but the wood is a natural object, and so is the iron of the nails. A watch is "made" of the natural objects, gold and other metals, sand, soda, rubies, brought together and shaped in various ways; a coat is "made" of the natural object wool, and a frock of the natural objects cotton

or silk. Moreover, the men who make all these things are natural objects.

Carpenters, builders, shoemakers, and all other artisans and artists, are persons who have learned so much of the powers and properties of certain natural objects, and of the chain of causes and effects in nature, as enables them to shape and put together those natural objects so as to make them useful to man.

A carpenter could not, as we say, "make" a chair unless he knew something of the properties and powers of wood; a blacksmith could not "make" a horseshoe unless he knew that it is a property of iron to become soft and easily hammered into shape when it is made red-hot; a brickmaker must know many of the properties of clay; and a plumber could not do his work unless he knew that lead has the properties of softness and flexibility, and that a moderate heat causes it to melt.

So that the practice of every art implies a certain knowledge of natural causes and effects; and the improvement of the arts depends upon our learning more and more of the properties and powers of natural objects, and discovering how to turn the properties and the powers of things, and the connections of cause and effect among them, to our own advantage.

7. Many Objects and Chains of Causes and Effects in Nature are Out of our Reach.

Among natural objects, as we have seen, there are some that we can get hold of and turn to account; but all the greatest things in nature, and the links of cause and effect which connect them, are utterly beyond our reach. The sun rises and sets; the moon and the stars move through the sky; fine weather and storms, cold and heat, alternate. The sea changes from violent disturbance to glassy calm as the winds sweep over it with varying strength or die away, innumerable plants and animals come into being and vanish again, without our being able to exert the slightest influence on the majestic procession of the series of great natural events. Hurricanes ravage one spot; earthquakes destroy another; volcanic eruptions lay waste a third. A fine season scatters wealth and abundance here, and a long drought brings pestilence and famine there. In all such cases the direct influence of man avails him nothing, and so long as he is ignorant he is the mere sport of the greater powers of nature.

8. The Order of Nature: Nothing Happens by Accident, and there is No Such Thing as Chance.

But the first thing that men learned, as soon as they began to study nature carefully, was that some events take place in regular order and

that some causes always give rise to the same effects. The sun always rises on one side and sets on the other side of the sky; the changes of the moon follow one another in the same order and with similar intervals; some stars never sink below the horizon of the place in which we live; the seasons are more or less regular; water always flows down hill; fire always burns; plants grow up from seed and yield seed, from which like plants grow up again; animals are born, grow, reach maturity, and die, age after age, in the same way. Thus the notion of an *order of nature* and of a fixity in the relation of cause and effect between things gradually entered the minds of men. So far as such order prevailed it was felt that things were explained; while the things that could not be explained were said to have come about by *chance*, or to happen by *accident*.

But the more carefully nature has been studied the more widely has order been found to prevail, while what seemed disorder has proved to be nothing but complexity, until at present no one is so foolish as to believe that anything happens by chance, or that there are any real accidents, in the sense of events which have no cause. And if we say that a thing happens by chance everybody admits that all we really mean is that we do not know its cause or the

reason why that particular thing happens. Chance and accident are only *aliases* of ignorance.

At this present moment, as I look out of my window, it is raining and blowing hard, and the branches of the trees are waving wildly to and fro. It may be that a man has taken shelter under one of these trees; perhaps, if a stronger gust than usual comes, a branch will break, fall upon the man, and seriously hurt him. If that happens it will be called an "accident," and the man will perhaps say that by "chance" he went out, and then "chanced" to take refuge under the tree, and so the "accident" happened.

But there is neither chance nor accident in the matter. The storm is the effect of causes operating upon the atmosphere perhaps hundreds of miles away. Every vibration of a leaf is the consequence of a mechanical force of the wind acting upon the surface exposed to it. If the bough breaks it will do so in consequence of the relation between its strength and the force of the wind. If it falls upon the man it will do so in consequence of the action of other definite natural causes, and the position of the man under it is only the last term in a series of causes and effects which have followed one another in natural order, from that cause the effect of which

was his setting out, to the effect of which was his stepping under the tree.

But inasmuch as we are not wise enough to be able to unravel all these long and complicated series of causes and effects which lead to the falling of the branch upon the man, we call such an event an accident.

9. Laws of Nature; Laws are Not Causes.

When we have made out by careful and repeated observation that something is always the cause of a certain effect, or that certain events always take place in the same order, we speak of the truth thus discovered as a *law of nature.* Thus it is a law of nature that anything heavy falls to the ground if it is unsupported; it is a law of nature that, under ordinary conditions, lead is soft and heavy, while flint is hard and brittle: because experience shows us that heavy things always do fall if they are unsupported; that, under ordinary conditions, lead is always soft and that flint is always hard.

In fact, everything that we know about the powers and properties of natural objects and about the order of nature may properly be termed a law of nature. But it is desirable to remember that which is very often forgotten: that the laws of nature are not the causes of the order of nature, but only our way of stating as

much as we have learned of that order. Stones do not fall to the ground in consequence of the law just stated, as people sometimes carelessly say; but the term is the way of asserting that which invariably happens when heavy bodies at the surface of the earth, stones among the rest, are free to move.

The laws of nature are, in fact, in this respect, similar to the laws which men make for the guidance of their conduct toward one another. There are laws about the payment of taxes, and there are laws against stealing or murder. But the law is not the cause of a man's paying his taxes, nor is it the cause of his abstaining from theft and murder. The law is simply a statement of what will happen to a man if he does not pay his taxes, and if he commits theft or murder; and the cause of his paying his taxes or abstaining from crime (in the absence of any better motive) is the fear of consequences—which is the effect of his belief in that statement. A law of man tells what we may expect society will do under certain circumstances; and a law of nature tells us what we may expect natural objects will do under certain circumstances. Each contains information addressed to our intelligence, and except so far as it influences our intelligence it is merely so much sound or writing.

While there is this much analogy between

human and natural laws, however, certain essential differences between the two must not be overlooked. Human law consists of commands addressed to voluntary agents, which they may obey or disobey, and the law is not rendered null and void by being broken. Natural laws, on the other hand, are not commands, but assertions respecting the invariable order of nature; and they remain laws only so long as they can be shown to express that order. To speak of the violation, or the suspension, of a law of nature is an absurdity. All that the phrase can really mean is that, under certain circumstances, the assertion contained in the law is not true; and the just conclusion is, not that the order of nature is interrupted, but that we have made a mistake in stating that order. A true natural law is a universal rule, and, as such, admits of no exceptions.

Again, human laws have no meaning apart from the existence of human society. Natural laws express the general course of nature, of which human society forms only an insignificant fraction.

10. Knowledge of Nature is the Guide of Practical Conduct.

If nothing happens by chance, but everything in nature follows a definite order, and if the laws of nature embody in accurate language that which we have been able to learn about the or-

der of nature, then it becomes very important for us to know as many as we can of these laws of nature, in order that we may guide our conduct by them.

Any man who should attempt to live in a country without reference to the laws of that country would very soon find himself in trouble; and if he were fined, imprisoned, or even hanged, sensible people would probably consider that he had earned his fate by his folly.

In like manner, anyone who tries to live upon the face of this earth without attention to the laws of nature will live there for but a very short time, most of which will be passed in exceeding discomfort; a peculiarity of natural laws, as distinguished from those of human enactment, being that they take effect without summons or prosecution. In fact, nobody could live for half a day unless he attended to some of the laws of nature; and thousands of us are dying daily, or living miserably, because men have not yet been sufficiently zealous to learn the code of nature.

It has already been seen that the practice of all our arts and industries depends upon our knowing the properties of natural objects which we can get hold of and put together; and though we may be able to exert no direct control over

the greater natural objects and the general succession of causes and effects in nature, yet if we know the properties and powers of these objects, and the customary order of events, we may elude that which is injurious to us and profit by that which is favorable.

Thus, though men can nowise alter the seasons or change the process of growth in plants, yet having learned the order of nature in these matters they make arrangements for sowing and reaping accordingly; they cannot make the wind blow, and when it does blow they take advantage of its known powers and probable direction to sail ships and turn windmills; they cannot arrest the lightning, but they can make it harmless by means of conductors—the construction of which implies a knowledge of some of the laws of that electricity of which lightning is one of the manifestations. Forewarned is forearmed, says the proverb; and knowledge of the laws of nature is forewarning of that which we may expect to happen when we have to deal with natural objects.

11. Science: the Knowledge of the Laws of Nature Obtained by Observation, Experiment, and Reasoning.

No line can be drawn between common knowledge of things and scientific knowledge; nor between common reasoning and scientific reasoning. In strictness, all accurate knowledge is

science and all exact reasoning is scientific reasoning. The method of *observation* and *experiment* by which such great results are obtained in science is identically the same as that which is employed by everyone, every day of his life, but refined and rendered precise. If a child acquires a new toy he observes its characters and experiments upon its properties; and we are, all of us, constantly making observations and experiments upon one thing or another.

But those who have never tried to observe accurately will be surprised to find how difficult a business it is. There is not one person in a hundred who can describe the commonest occurrence with even an approach to accuracy. That is to say, either he will omit something which did occur, and which is of importance, or he will imply or suggest the occurrence of something which he did not actually observe, but which he unconsciously infers must have happened. When two truthful witnesses contradict one another in a court of justice it usually turns out that one or other, or sometimes both, are confounding their inferences from what they saw with that which they actually saw. A swears that B picked his pocket. It turns out that all that A really knows is that he felt a hand in his pocket when B was close to him; and that B was not the thief, but C, whom A

did not observe. Untrained observers mix up together their inferences from what they see with that which they actually see in the most wonderful way; and even experienced and careful observers are in constant danger of falling into the same error.

Scientific observation is such as is at once full, precise, and free from unconscious inference.

Experiment is the observation of that which happens when we intentionally bring natural objects together, or separate them, or in any way change the conditions under which they are placed. Scientific experiment, therefore, is scientific observation performed under accurately known artificial conditions.

It is a matter of common observation that water sometimes freezes. The observation becomes scientific when we ascertain under what exact conditions the change of water into ice takes place. The commonest experiments tell us that wood floats in water. Scientific experiment shows that, in floating, it displaces its own weight of the water.

Scientific *reasoning* differs from ordinary reasoning in just the same way as scientific observation and experiment differ from ordinary observation and experiment—that is to say, it strives to be accurate; and it is just as hard to reason accurately as it is to observe accurately.

In scientific reasoning general rules are collected from the observation of many particular cases, and when these general rules are established conclusions are deduced from them; just as in everyday life. If a boy says that "marbles are hard," he has drawn a conclusion as to marbles in general from the marbles he happens to have seen and felt, and has reasoned in that mode which is technically termed *induction*. If he declines to try to break a marble with his teeth it is because he consciously, or unconsciously, performs the converse operation of *deduction* from the general rule "marbles are too hard to break with one's teeth."

You will learn more about the process of reasoning when you study *Logic*, which treats of that subject in full. At present it is sufficient to know that the laws of nature are the general rules respecting the behavior of natural objects, which have been collected from innumerable observations and experiments; or, in other words, that they are inductions from those observations and experiments. The practical and theoretical results of science are the products of deductive reasoning from these general rules.

Thus science and common sense are not opposed, as people sometimes fancy them to be, but science is perfected common sense. Scientific reasoning is simply very careful common

reasoning, and common knowledge grows into scientific knowledge as it becomes more and more exact and complete.

The way to science, then, lies through common knowledge. We must extend that knowledge by careful observation and experiment, and learn how to state the results of our investigations accurately in general rules, or laws, of nature; finally, we must learn how to reason accurately from these rules, and thus arrive at rational explanations of natural phenomena which may suffice for our guidance in life.

II

About Common Water

By PROFESSOR JOHN TYNDALL, F.R.S.

I PROPOSE to talk to you for about half an hour about water in its common and domestic forms. On the importance of water it is not necessary to dwell, for it is obvious that upon its presence depends the life of the world. As an article of human diet its importance is enormous. Not to speak of fruits and vegetables, and confining ourselves to flesh, every four pounds of boneless meat purchased at the butcher's shop contain about three pounds of water. I remember Mr. Carlyle once describing an author, who was making a great stir at the time, as "a weak, watery, insipid creature." But in a literal and physical sense we are all "watery." The muscles of a man weighing one hundred and fifty pounds weigh, when moist, sixty-four pounds, but of these nearly fifty pounds are mere water.

It is not of the water compacted in the tissues of a man that I am now going to speak, but of the ordinary water which we see everywhere around us. Whence comes our drinking water? A little reflection might enable you to reply, "If you go back far enough you will find that it

comes from the clouds, which send their rain down upon the earth." "But how," it may be asked, "does the water get up into the cloud region?" Your reply will probably be, "It is carried up by evaporation from the waters of the earth."

A great Roman philosopher and poet, named Lucretius, wrote much about *atoms*, which he called "the First Beginnings." When it was objected that nobody could see the atoms he reasoned in this way: "Hang out a wet towel in the sun, and after some time you will find that all the water has gone away. But you cannot see the particles of the water that has thus disappeared. Still it is perfectly certain that the water, which when put into the towel could be seen, and felt, and tasted, and weighed, must have escaped from the towel in this invisible way. How, then, can you expect me to show you the atoms, which, as they are the first beginnings of things, are probably much smaller than your 'invisible particles of water?'"

In this invisible state to which water may be reduced it is called aqueous vapor.

Let it be admitted that water rises into the air by evaporation; and that in the air it forms the clouds which discharge themselves upon us as rain, hail, and snow. If you look for the

source of any great American river you will find it in some mountain-land where, in its infancy, it is a mere stream. Added to gradually, by other tributary streams, it becomes broader and deeper, until finally it reaches the noble magnitude of the Mississippi or the Ohio. A considerable portion of the rain water sinks into the earth, trickles through its pores and fissures, coming here and there to light as a pellucid spring. We have now to consider how "spring water" is affected by the rocks, or gravel, or sand, or soil, through which it passes. Mrs. Tyndall and myself are lovers of the highlands. I tried last year to give some notion of "Life in the Alps." Well, here in England Alpine heights are not attainable, but we have built our house upon the highest available land within two hours of London. Thousands of acres of heather surround us, and storms visit us more furious than those of the Alps. The reason is, that we are on the very top of Hind Head, where the wind can sweep over us without impediment.

There is no land above our house, and therefore there are no springs at hand available for use. But lower down, in the valleys, the springs burst forth, providing the people who live near them with the brightest and purest water. These happy people have all my land

and all the high surrounding land as a collecting ground, on which the rain falls and from which it trickles, through the body of the hill, to appear at lower levels. What, then, am I obliged to do? It stands to reason that, if I could bore down to a depth lower than the springs, the water instead of flowing to them would come to me.

The water drawn from this well comes from what geologists call the greensand. Within sight of my balcony rise the well-known South Downs, which are hills of chalk covered with verdure. Now, if a bucket of water were taken from my well, and a similar bucket from a well in South Downs, and if both buckets were handed over to a laundress, she would have no difficulty in telling you which she would prefer. With my well water it would be easy to produce a beautiful lather. With the South Downs well water it would be very difficult to do so. In common language, the one water is *soft*, like rain water, while the other is *hard*.

We have now to analyze and understand the meaning of "hard water" and to examine some of its effects. Suppose, then, three porcelain basins to be filled, the first with the purest rain water, the second with greensand water, and the third with chalk water; all three waters at first being equally bright and trans-

parent. Suppose the three basins to be placed on a warm hob, or even exposed to the open air until the water of each basin is wholly evaporated. In evaporation the water only disappears; the mineral matter remains. What, then, is the result? In the rain water basin you have nothing left behind; in the greensand water basin you have a small residue of solid mineral matter; in the chalk water basin you have a comparatively large residue. The reason of this is that chalk is soluble in rain water, and dissolves in it like sugar or salt, though to a far less extent; while the water of my well, coming from the greensand, which is hardly soluble at all, is almost as soft as rain water. The simple boiling of water is sufficient to precipitate a considerable portion of mineral matter dissolved in it. One familiar consequence is that kettles and boilers in which hard water is used become rapidly incrusted, while no such incrustation is formed by soft water. Hot-water pipes are sometimes choked by such incrustation; and the boilers of steamers have been known to be so thickly coated as to prevent the access of heat to the water within them. Not only was their coal thus wasted, but it has been found necessary in some cases to burn the very spars in order to bring the steamers into port.

There is no test of the presence of suspended matter in water or air so searching and powerful as a beam of light. An old English writer touched this point when he said, "The sun discovers atoms, though they be invisible by candle light, and makes them dance in his beams." In the purest water—it may be filtered water, it may be artificially distilled water, it may be water obtained by melting the purest ice—a sufficiently strong searching beam reveals suspended matter.

Differences in quantity are, however, strikingly revealed. When, in a darkened study, I send a concentrated beam through our well water, after boiling, it appears turbid; sent through the South Downs well water it appears muddy, so great is the quantity of chalk precipitated by boiling. The mere exposure of hard water to the air, where it can evaporate, softens it considerably by the partial precipitation of mineral matter which it held in solution.

This last observation is important, because it enables us to explain many interesting effects. In chalybeate springs iron is dissolved in the water. Round about such springs and along the rivulets that flow from them red oxide of iron—iron rust—is precipitated by the partial evaporation of the water. In Iceland the water of the great geyser holds a considerable quantity of flint or

silica in solution. By a most curious process of evaporation this silica, as shown by Bunsen, has been so deposited as to enable what was at first a simple spring to build up gradually the wonderful tube of the geyser, which is seventy-four feet deep and ten feet across, with a smooth basin, sixty feet wide, at the top.

Again, the great majority of our grottos and caves are in limestone rock, which, in the course of ages, has been dissolved away by a stream. To the present hour are to be found in most of these caves the streams which made them. I have been through many of them, but none can compare in beauty with St. Michael's Cave in Gibraltar. From the roof hang tapering stalactites like pointed spears. From the floor rise columnar stalagmites. The stalactites gradually lengthen, while the stalagmites gradually rise. In numerous cases stalactite and stalagmite meet. Columns of singular beauty, reaching from floor to roof, are thus formed. Stalactites and stalagmites are to be seen in all phases of their approach toward each other; from the little spear, beginning like a small icicle, and the little mound of stalagmite on the floor, exactly underneath, up to the actual contact of both. The pillars and spears, arches and corridors, the fantastic stone draperies, the fretted figures on the walls, all

contribute to produce an effect of extraordinary magnificence.

What is the cause of this wonderful architecture of St. Michael's Cave? Probably some of my clever readers will have anticipated both this question and its answer. The rain, charged with its carbonic acid, falls upon the limestone rock overhead, percolates through it, dissolves it, and thus laden reaches the roof of the cave. Here it is exposed to evaporation, the dissolved solid in part deposited, and the base of the stalactite is planted against the roof. The charged water continues to drip, and the stalactite to lengthen. Escaping from the point of the stalactite, the drop falls upon the floor where evaporation continues and mineral matter is deposited. The stalagmite rises; the mound becomes a pillar, toward which the spear overhead accurately points, until, in the course of time, they unite to form a column. A similar process goes on over the fretted walls. Each water film deposits its infinitesimal load, the quantity deposited here and there depending on the inequalities of the surface, which cause the water to linger longer and to deposit more at some places than at others. The substance most concerned in the production of all this beauty is called by chemists carbonate of lime. It is formed by the union of carbonic acid and lime.

What lime is, of course you already know; its companion, carbonic acid, is at ordinary temperatures a very heavy gas. It effervesces in soda water and constitutes a portion of the breath exhaled from the lungs. The weight of the gas as compared with the air may be actually determined by the chemist's balance.

But its weight may also be shown in the following way. Let a wide glass shade be turned upside down and filled with carbonic acid gas. This is readily done, though when done you do not see the gas. Well, iron sinks in water, because it is heavier than water; it swims on mercury, because it is lighter than mercury. For the same reason if you blow a soap bubble and dexterously shake it off, so that it shall fall into the the glass shade, it floats on the *carbon di oxid*, bobbing up and down as if on an invisible elastic cushion. The light air floats on the heavy gas. Almost any other acid poured upon chalk or marble liberates the carbonic acid. Its grasp of the lime is feeble and easily overcome. When we dissolve and mix a common soda powder, the tartaric acid turns the weaker carbonic acid out of doors. Many natural springs of carbonic acid have been discovered, one of which I should like to introduce to your notice. In the neighborhood of the city of Naples there is a cave called the *Grotto del Cane*, a name given to it for a curi-

ous and culpable reason. During one of the eruptions of Vesuvius I paid a visit, in company with two friends, to Naples, and went to see, among other sights of that wonderful region, the Grotto of the Dog. At a place adjacent we met a guide and some other visitors. At the heels of the guide was a timid little quadruped which for the time being gave the cave its name. We could walk into the cave without inconvenience, knowing, at the same time, from the descriptions we had heard and read, that our feet were plunged in a stream of heavy carbonic acid flowing along the bottom of the cave. The poor little dog was, much against its will, brought into the grotto. The stream of carbonic acid was not deep enough to cover the animal; its master accordingly pressed its head under the suffocating gas. It struggled for a time, but soon became motionless—apparently lifeless. Taken into the the air outside, through a series of convulsions, painful to look upon, it returned to life.

The experiment is a barbarous one, and ought not to be tolerated. There are many ways of satisfying the curious without cruelty to the dog. I made the following experiment, which seemed to surprise the bystanders. Placing a burning candle near the bottom of my hat, in the open air outside the cave, I borrowed a cap, by means of which I ladled up the heavy

gas. Pouring it from the cap into the hat, the light was quenched as effectually as if water had been poured upon it. Made with glass jars instead of hats, this is a familiar laboratory experiment.

We must now proceed slowly forward, making our footing sure as we advance. Lime is sparingly soluble in water, giving it a strong acrid taste. Limewater is as clear as ordinary water; the eye discerns no difference between them. And now I want to point out to you one of the ways in which the carbonate of lime, which we have been speaking of, may be formed.

I suppose you have before you a tumbler or a beaker filled with clear limewater. By means of a pair of bellows, to the nozzle of which a glass tube is attached, you can cause pure air to bubble through the limewater. It continues clear. You have just been informed that the breath exhaled from the lungs contains carbonic acid, and if this acid be brought into contact with lime, carbonate of lime will be formed. Knowing this, you can make the following experiment: Drawing your breath inward so as to fill your lungs, you breathe by means of the glass tube, through the limewater. Before you have emptied your lungs the clear limewater will have become milky, the milkiness being

due to fine particles of carbonate of lime—otherwise chalk—formed by the union of the carbonic acid of your breath with the water.

We now come to the point of great practical importance. The carbonate of lime exists in two forms: the simple carbonate, of which chalk is an example, which embraces a certain amount of carbonic acid, and the bicarbonate, which contains twice as much. But the bicarbonate is far more soluble in water than the simple carbonate. Pure water dissolves only an extremely small quantity of the simple carbonate of lime. But carbonic acid is sparingly diffused everywhere throughout our atmosphere, and rain water always carries with it, from the air, an amount of carbonic acid which converts the simple carbonate of the chalk into the bicarbonate, of which it can dissolve a considerable quantity. Every gallon of water, for example, taken from the chalk contains more than twenty grains of the dissolved mineral.

By boiling or by evaporation this bicarbonate is reconverted into the insoluble carbonate, which renders our flasks of boiled chalk water turbid, forms incrustations in our kettles, and deposits itself as stalactites and stalagmites in our limestone caves. But there is another way of converting the bicarbonate into the carbonate which is well worthy of attention. It will show

how a man of science thinks before he experiments, and how by experiment he afterward verifies his thought. Bearing in mind that the chalk springs hold lime in solution as the bicarbonate, it is plain that if we could rob this bicarbonate of half of its carbonic acid we should reduce it to the simple carbonate, which is wholly insoluble.

Think the matter over a little. What we have to do is to combat an excess of carbonic acid. Limewater without any carbonic acid is easily prepared. Suppose, then, that we add to our chalk water, with its double dose of carbonic acid, some pure limewater, what would you expect? You would, at all events, think it probable that the bicarbonate of the chalk water would give up its excess of carbonic acid to the lime, and assume the position of the simple carbonate, which because of its insolubility would be precipitated as a white powder in the water. And, because chalk is heavier than water, you would conclude that the powder would sink to the bottom, leaving a clear, softened water overhead. Thus reasoned Dr. Clark, of Aberdeen, when he invented his beautiful process of softening water on a large scale. I have myself seen the process applied with success in various chalk districts in England.

Let us make a calculation. Every pound of chalk contains nine ounces of lime and seven

ounces of carbonic acid. Dissolved by rain water, this simple carbonate becomes bicarbonate, where every nine ounces of lime combine with fourteen ounces of carbonic acid. If, then, a quantity of pure limewater containing nine ounces of lime be added to these twenty-three ounces of bicarbonate solution, the lime will seize upon seven ounces of the fourteen, and form two pounds of the nearly insoluble carbonate. In other words, nine ounces of lime can precipitate thirty-two ounces of chalk. Counting thus on a large scale, we find that a single ton of lime, dissolved in limewater, suffices to precipitate three and a half tons of the simple carbonate.

Let me now describe to you what I saw at Canterbury, where are works for the softening of water. I found there three reservoirs, each capable of containing one hundred and twenty thousand gallons of water. There was also a fourth, a smaller cistern, containing water and lime in that state of fine division which is called "cream of lime." The mixture of water and lime is violently stirred up by currents of air driven through it. Brought thus into intimate contact with every particle, the water soon takes up all the lime it can dissolve. The mixture is then allowed to stand; the solid lime falls to the bottom, and the pure limewater collects overhead.

The softening process begins by introducing a measured quantity of this limewater into one of the larger cisterns. The hard water, pumped directly from the chalk, is then permitted to fill the cistern. When they come together, the two clear liquids form a kind of thin whitewash, which is permitted to remain quiet for twelve or, still better, for twenty-four hours. The carbonate of lime sinks to the bottom of the reservoir, covering it as a fine white powder, while above is a water of extreme softness and transparency, and of the most delicate blue color. This water harbors no organisms. Properly conducted to our homes, no infectious fever could ever be propagated by such water.

Blue is the natural color of both water and ice. On the glaciers of Switzerland I found deep shafts and lakes of beautifully blue water. The most striking example of the color of water is probably that furnished by the Blue Grotto of Capri, in the Bay of Naples. Capri is one of the islands of the bay. At the bottom of one of its sea cliffs there is a small arch, barely sufficient to admit a boat in fine weather, and through this arch you pass into a spacious cavern the walls and water of which shimmer forth a magical blue light. This light has caught its color from the water through which it has passed. The entrance, as just stated, is very

small, so that the illumination of the cave is almost entirely due to light which has plunged to the bottom of the sea, and returned thence to the cave. Hence the exquisite azure. The white body of a diver who plunges into the water for the amusement of visitors is also strikingly affected by the colored liquid through which he moves.

Water yields so freely to the hand that you might suppose it to be easily squeezed into a smaller space. That this is not the case was proved more than two hundred and sixty years ago by Lord Bacon. He filled a hollow globe of lead with the liquid, and, soldering up the aperture, tried to flatten the globe by the blows of a heavy hammer. He continued hammering "till the water, impatient of further pressure, exuded through the solid lead like a fine dew." Water was thus proved to offer an immense resistance to compression. Nearly fifty years afterward a similar experiment, with the same result, was made by the members of the Academy del Cimento, in Florence. They, however, used a globe of silver instead of a globe of lead. This experiment is everywhere known as "the Florentine experiment;" but Ellis and Spedding, the eminent biographers of Bacon, have clearly shown that it ought to be called "the Baconian experiment."

This stubbornness of water in the liquid condition has a parallel in its irresistible force when passing from the liquid into the solid state. Water expands in solidifying; and ice floats on water in consequence of this expansion. The wreck of rocks upon the summits of some mountains is extraordinary. Under the guise of freezing water a giant stonebreaker has been at work upon these heights. By his remorseless power even the great and fatal pyramid of the Matterhorn is smashed and riven from top to bottom. I once lay in a tent near a gully of the Matterhorn and heard all night long the thunderous roar of the stone avalanches which sweep incessantly down this mountain.

On the slopes surrounding our Alpine home we find heaps and mounds where slabs and blocks are piled together in apparent confusion; but we soon come to the sure and certain conclusion that these severed pieces are but parts of a once coherent rock, which has been shattered by the freezing of water in its fissures and its pores.

A favorite excursion of ours in Switzerland takes us along a noble glacier to the base of the great final pyramid of the Aletschhorn. There a few years ago was to be found a huge rock with a horizontal upper surface so spacious that twenty of us have sometimes lunched together

upon it. Literally as well as technically it was a noble "glacier table." That great bowlder of apparently iron strength is now reduced to fragments by the universal pulverizer—freezing water. I say pulverizer; for, over and above its work of destruction upon the mountains, has it not disintegrated the bare rocks of the ancient earth and thus produced the soils which constitute the basis of the whole vegetable world?

When water passes from the liquid to the solid condition it is usually by a process of architecture so refined as to baffle our most powerful microscopes. I never observe without wonder this crystalline architecture. Look at it on the windowpanes, or on the flags over which you walk on a frosty morning. Nothing can exceed the beauty of the branching forms that overspread the chilled surfaces. Look at the feathery plumes that sometimes sprout from wood, or cloth, or porous stones. The reflecting mind cannot help receiving from this definite grouping and ordering of the ultimate particles of matter suggestions of the most profound significance.

Many months ago I read a stanza from your delightful poet, Bryant, wherein he refers to the "stars" of snow. Those stellar forms of fallen snow repeat themselves incessantly. I have seen the Alps in midwinter laden with these fal-

len stars; and three or four days ago, they showered their beauty down upon me in England.

The ice crystal is hexagonal in form, and the snow stars invariably shoot forth six rays. The hexagonal architecture is carried on in the formation of common ice. Some years ago I set a large lens in the sun, and brought the solar rays to a focus in the air. I then placed a slab of pure ice across the convergent beam. Sparks of light, apparently generated by the beam, immediately appeared along its track.

Examining the ice afterward with a magnifying lens, I found that every one of those brilliant points constituted the center, or nucleus, of a beautiful liquid flower of six petals. There is no deviation from this number, because it was inexorably bound up with the crystalline form of the ice.

Thus, in a region withdrawn from the inattentive eye, we find ourselves surprised and fascinated by the methods of Nature.

III

The History of a Piece of Coal

Adapted from *The Fairyland of Science*, by ARABELLA B. BUCKLEY

I HAVE here a piece of coal (Fig. 1), which, though it has been cut with some care, so as to have a smooth face, is really in no other way different from any ordinary lump which you can pick for yourself out of the coal scuttle. Our

Fig. 1.

Piece of Coal.

a, Smooth face, showing laminæ or thin layers.

work is to relate the history of this black lump; to learn what it is, what it has been, and what it will be.

It looks uninteresting enough at first sight, and yet if we examine it closely we shall find some questions to ask even about its appearance.

Look at the smooth face of this specimen and see if you can explain those fine lines which run across so close together as to look like the edges of the leaves of a book. Try to break a piece of coal, and you will find that it will split much more easily along those lines than across the other way of the lump; and if you wish to light a fire quickly you should always put this lined face downward, so that the heat can force its way up through these cracks and gradually split up the block. Then, again, if you break the coal carefully along one of these lines you will find a fine film of charcoal lying in the crack, and you will begin to suspect that this black coal must have been built up in very thin layers, with a kind of black dust between them.

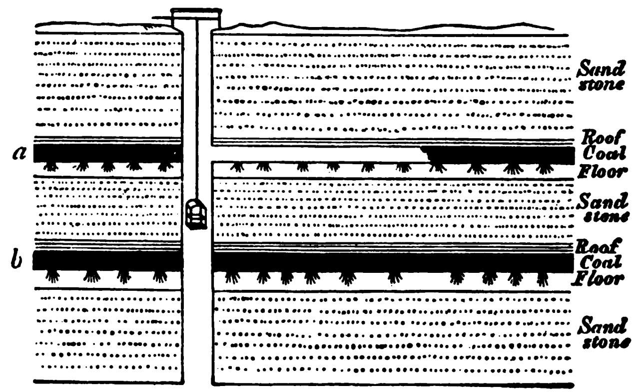
The next thing you will call to mind is that this coal burns and gives flame and heat, and that this means that in some way sunbeams are imprisoned in it; lastly, this will lead you to think of plants, and how they work up the strength of the sunbeams into their leaves, and hide black carbon in even the purest and whitest substance they contain.

Is coal made of burnt plants then? Not burnt ones, for if so it would not burn again; but you may have read how the makers of charcoal take wood and bake it without letting it burn, and then it turns black and will afterward make a

very good fire; and so you will see that it is probable that our piece of coal is made of plants which have been baked and altered, but which have still much sunbeam strength bottled up in them, which can be set free as they burn.

If you will take an imaginary journey with me to a coal pit near Newcastle, which I visited

Fig. 2.



Imaginary Section of a Coal Mine.

many years ago, you will see that we have very good evidence that coal is made of plants, for in all coal mines we find remains of them at every step we take.

Let us imagine that we have put on old clothes which will not spoil, and have stepped into the iron basket (see Fig. 2) called by the miners a *cage*, and are being let down the shaft to the

gallery where the miners are at work. Most of them will probably be in the gallery *b*, because a great deal of the coal in *a* has been already taken out. But we will stop in *a* because there we can see a great deal of the roof and the floor. When we land on the floor of the gallery we shall find ourselves in a kind of tunnel with railway lines laid along it and trucks laden with coal coming toward the cage to be drawn up, while empty ones are running back to be loaded where the miners are at work. Taking lamps in our hands and keeping out of the way of the trucks, we will first throw the light on the roof, which is made of shale or hardened clay. We shall not have gone many yards before we see impressions of plants in the shale, like those in this specimen (Fig. 3), which was taken out of a coal mine at Neath in Glamorganshire. You will recognize at once the marks of *ferns* (*a*), for they look like those you gather in the hedges of an ordinary country lane, and that long striped branch (*b*) does not look unlike a reed, and indeed it is something of this kind, as we shall see by and by. You will find plenty of these impressions of plants as you go along the gallery and look up at the roof, and with them there will be others with spotted stems, or with stems having a curious diamond pattern upon them, and many ferns of various kinds.

Next look down at your feet and examine the floor. You will not have to search long before

Fig. 3.

A Piece of Shale with Impressions of Ferns and Calamite Stems.

you will almost certainly find a piece of stone like that represented in Fig. 4, which has also

Fig. 4.

Stigmaria—Root or Underground Stem of Sigillaria.

come from Neath colliery. This fossil, which is the cast of a piece of a plant, puzzled those

who found it for a very long time. At last, however, Mr. Binney found the specimen growing to the bottom of the trunk of one of the fossil trees with spotted stems, called *Sigillaria*, and so proved that this curious pitted stone is a piece of fossil root, or rather underground stem, like that which is found in the primrose, and that the little pits or dents in it are scars where the rootlets once were given off.

Whole masses of these root stems, with ribbonlike roots lying scattered near them, are found buried in the layer of clay called the *underclay* which makes the floor of the coal, and they prove to us that this underclay must have been once the ground in which the roots of the coal plants grew. You will feel still more sure of this when you find that there is not only one straight gallery of coal, but that galleries branch out right and left, and that everywhere you find the coal lying like a sandwich between the floor and the roof, showing that quite a large piece of country must be covered by these remains of plants all rooted in the *underclay*.

But how about the coal itself? It seems likely, when we find roots below and leaves and stems above, that the middle is made of plants, but can we prove it? We shall see presently that it has been so crushed and altered by being buried deep in the ground that the traces of

leaves have almost been destroyed, though people who are used to examining with the microscope can see the crushed remains of plants in thin slices of coal.

But fortunately for us, perfect pieces of plants have been preserved even in the coal bed itself. Do you remember learning that water with lime in it petrifies things; that is, leaves carbonate of lime to fill up, grain by grain, the fibers of an animal or plant as the living matter decays, and so keeps an exact representation of the object?

Now, it so happens that in a coal bed at South Ouram, near Halifax, England, as well as in some other places, carbonate of lime trickled in before the plants were turned into coal, and made some round nodules in the plant bed which look like cannon balls. Afterward, when all the rest of the bed was turned into coal, these round balls remained crystallized, and by cutting thin transparent slices across the nodule we can distinctly see the leaves and stems and curious little round bodies which make up the coal. Several such sections may be seen at the British Museum. And when we compare these fragments of plants with those which we find above and below the coal bed we find that they agree, thus proving that coal is made of plants, and of those plants whose roots grew in the clay floor while their heads reached up far above where the roof now is.

The next question is, What kind of plants were these? Have we anything like them living in the world now? You might perhaps think that it

Fig. 5.

Contents of a Coal Ball. (Carruthers.)

S, Stem of Sigillaria cut across. *L*, Stem of Lepidodendron cut across. *L'*, Stem of Lepidodendron cut lengthways. *l*, Cone of Lepidodendron (Lepidostrobus) cut across. *C*, Stem of Calamite cut across. *c*, *c*, *c*, Fruit of Calamite lengthways and across. *f*, Stem of a fern with fragments of fern leaves scattered round it. The small round dots scattered here and there are the larger spores which have fallen out of the fruit cones.

would be impossible to decide this question from mere petrified pieces of plants. But many men have spent their whole lives in deciphering all

the fragments that could be found, and though the section given in Fig. 5 may look to you quite incomprehensible, yet a botanist can read it as we read a book. For example, at *S* and *L*, where stems are cut across, he can learn exactly how they were built up inside, and compare them with the stems of living plants, while the fruits

Fig. 6.

Selaginella Selaginoides. Species of Club Moss Bearing two kinds of Spores.

c, *c*, and the little round spores lying near them, tell him their history as well as if he had gathered them from the tree. In this way we have learned to know very fairly what the plants of the coal were like, and you will be surprised

when I tell you that the huge trees of the coal forests, of which we sometimes find trunks in the coal mines from ten to fifty feet long, are only represented on the earth now by small insignificant plants, scarcely ever more than two feet, and often not many inches high.

Have you ever seen a little club moss or Lycopodium which grows all over England, but chiefly in the north, on heaths and mountains? At the end of each of its branches it bears a cone made of scaly leaves; and fixed to the inside of each of these leaves is a case called a sporangium, full of little spores or moss seeds, as we call them, though they are not exactly like true seeds. In one of these club mosses called *Selaginella* (Fig. 6), the cases *B*, near the bottom of the cone, contain large spores, *b*, while those near the top, *A*, contain a powdery dust *a*. These spores are full of resin, and they are collected on the Continent for making artificial lightning in the theaters, because they flare when lighted.

Now this little Selaginella is of all living plants the one most like some of the gigantic trees of the coal forests. If you look at this picture of a coal forest (Fig. 7) you will find it difficult perhaps to believe that those great trees, with diamond markings all up the trunk, hanging over from the right to the left of the picture and covering all the top with their boughs, could

Fig. 7.

A Forest of the Coal Period.

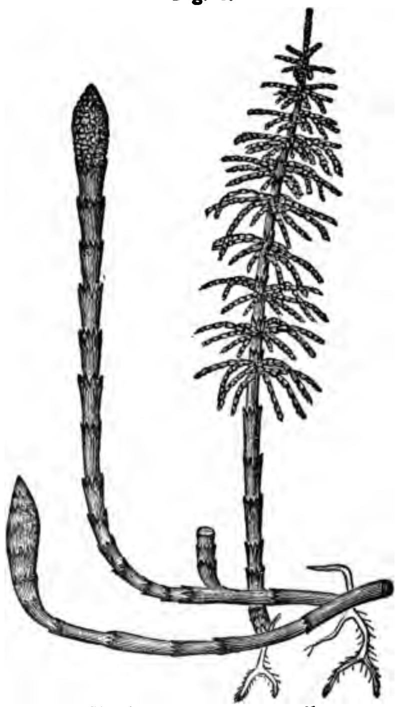
be in any way relations of the little Selaginella; yet we find branches of them in beds above the coal-bearing cones larger but just like Selaginella cones, and—what is most curious—the spores in these cones are of exactly the same kind and not any larger than those of the club moss.

These trees are called by botanists Lepidodendrons, or *scaly trees;* there are numbers of them in all coal mines, and one trunk has been found forty-nine feet long. Their branches were divided in a curious forked manner and bore cones at the ends. The spores which fell from these cones are found flattened in the coal, and they may be seen scattered about in the coal ball (Fig. 5).

Another famous tree which grew in the coal forests was the one whose roots we found in the floor or *underclay* of the coal. It has been called Sigillaria, because it has marks like seals (*sigillum*, a seal) all up the trunk, due to the scars left by the leaves when they fell from the tree. You will see the Sigillarias on the left-hand side of the coal forest picture, having those curious tufts of leaves springing out of them at the top. Their stems make up a great deal of the coal, and the bark of their trunks is often found in the clays above, squeezed flat in lengths of thirty, sixty, or seventy feet. Sometimes instead of being flat the bark is still in the shape of a trunk

and the interior is filled with sand; and then the trunk is very heavy, and if the miners do not prop the roof up well it falls down and kills

Fig. 8.



Equisetum, or Horsetail.

those beneath it. Stigmaria (Fig. 4) is the root of the Sigillaria, and is found in the clays below the coal. Botanists are not yet quite certain about the seed cases of this tree, but Mr. Car-

ruthers believes that they grew inside the base of the leaves, as they do in the quillwort, a small plant which grows at the bottom of our mountain lakes.

But what is that curious reedlike stem we found in the piece of shale (see Fig. 3)? That stem is very important, for it belonged to a plant called a *Calamite*, which, as we shall see presently, helped to sift the earth away from the coal and keep it pure. This plant was a near relation of the "horsetail," or Equisetum, which grows in our marshes; only, just as in the case of the other trees, it was enormously larger, being often twenty feet high, whereas the little Equisetum (Fig. 8) is seldom more than a foot, and never more than four feet high in England, though in tropical South America they are much higher. Still, if you have gathered "horsetails" you will see at once that those trees in the foreground of the picture (Fig. 7), with leaves arranged in stars around the branches, are only larger copies of the little marsh plants, and the seed vessels of the two plants are almost exactly the same.

These great trees, the Lepidodendrons, the Sigillarias, and the Calamites, together with large tree ferns and smaller ferns, are the chief plants that we know of in the coal forests. It seems very strange at first that they should have been

so large when their descendants are now so small, but if you look at our chief plants and trees now, you will find that nearly all of them bear flowers, and this is a great advantage to them, because it tempts the insects to bring them the pollen dust.

Now the Lepidodendrons and their companions have no true flowers, but only the seed cases which we have mentioned; but as there were no flowering plants in their time, and they had the ground all to themselves, they grew fine and large. By and by, however, when the flowering plants came in, these began to crowd out the old giants of the coal forests, so that they dwindled and dwindled from century to century, till their great-great-grandchildren, thousands of generations after, only lift up their tiny heads in marshes and on heaths, and tell us that they were big once upon a time.

And indeed they must have been magnificent in those olden days, when they grew thick and tall in the lonely marshes where plants and trees were the chief inhabitants. We find no traces in the clay beds of the coal to lead us to suppose that men lived in those days, nor lions, nor tigers, nor even birds to fly among the trees; but these grand forests were almost silent, except when a huge animal something like a gigantic newt or frog went croaking through the

marsh, or a kind of grasshopper chirruped on the land. But these forms of life were few and far between, compared to the huge trees and tangled masses of ferns and reeds which covered the whole ground, or were reflected in the bosom of the large pools and lakes round about which they grew.

And now if you have some idea of the plants and trees of the coal, it is time to ask how these plants became buried in the earth and made pure coal, instead of decaying away and leaving behind only a mixture of earth and leaves?

To answer this question, I must ask you to take another imaginary journey with me, to the Atlantic shores of America, and to land at Norfolk in Virginia, because there we can see a state of things something like the marshes of the coal forests. All around about Norfolk the land is low, flat, and marshy, and to the south of the town, stretching far away into North Carolina, is a large, desolate swamp, no less than forty miles long and twenty-five broad. The whole place is one enormous quagmire, overgrown with water plants and trees. The soil is as black as ink from the old, dead leaves, grasses, roots, and stems which lie in it; and so soft that everything would sink into it if it were not for the matted roots of the mosses, ferns, and other plants that bind it together. You may dig down

for ten or fifteen feet and find nothing but peat made of the remains of plants which have lived and died there in succession for ages and ages, while the black trunks of the fallen trees lie here and there, gradually being covered up by the dead plants.

The whole place is so still, gloomy, and desolate that it goes by the name of the "Great Dismal Swamp," and you see we have here what might well be the beginning of a bed of coal; for we know that peat, when dried, becomes firm and makes an excellent fire, and if it were pressed till it was hard and solid it would not be unlike coal. If, then, we can explain how this peaty bed has been kept pure from earth we shall be able to understand how a coal bed may have been formed, even though the plants and trees which grow in this swamp are different from those which grew in the coal forests.

The explanation is not difficult; streams flow constantly, or rather ooze into the Great Dismal Swamp from the land that lies to the west, but instead of bringing mud in with them as rivers bring to the sea, they bring only clear, pure water, because, as they filter for miles through the dense jungle of reeds, ferns, and shrubs which grow around the marsh, all the earth is sifted out and left behind. In this way the spongy mass of dead plants remains free from

earthy grains, while the water and the shade of the thick forest of trees prevent the leaves, stems, etc., from being decomposed by the air and sun. And so year after year as the plants die they leave their remains for other plants to take root in, and the peaty mass grows thicker and thicker, while tall cedar trees and evergreens live and die in these vast swampy forests, and being in loose ground are easily blown down by the wind, and leave their trunks to be covered up by the growing moss and weeds.

Now we know that there were plenty of ferns and of large Calamites growing thickly together in the coal forests, for we find their remains everywhere in the clay, so we can easily picture to ourselves how the dense jungle formed by these plants would fringe the coal swamp, as the present plants do the Great Dismal Swamp, and would keep out all earthy matter, so that year after year the plants would die and form a thick bed of peat, afterward to become coal.

The next thing we have to account for is the bed of shale or hardened clay covering over the coal. Now we know that from time to time land has gone slowly up and down, on our globe, so as in some places to carry the dry ground under the sea and in others to raise the sea bed above the water. Let us suppose, then, that the great Dismal Swamp was gradually to sink

down so that the sea washed over it and killed the reeds and shrubs. Then the streams from the west would not be sifted any longer, but would bring down mud, and leave it, as in the delta of the Nile or Mississippi, to make a layer over the dead plants. You will easily understand that this mud would have many pieces of dead trees and plants in it which were stifled and died as it covered them over; and thus the remains would be preserved like those which we find now in the roof of the coal galleries.

But still there are the thick sandstones in the coal mine to be explained. How did they come there? To explain them we must suppose that the ground went on sinking till the sea covered the whole place where once the swamp had been, and then sea sand would be thrown down over the clay and gradually pressed down by the weight of new sand above till it formed solid sandstone, and our coal bed became buried deeper and deeper in the earth.

At last, after long ages, when the thick mass of sandstones above the bed *b* (Fig. 2) had been laid down, the sinking must have stopped and the land have risen a little, so that the sea was driven back; and then the rivers would bring down earth again and make another clay bed. Then the new forest would spring up, the ferns, Calamites, Lepidodendrons, and Sigillarias

would gradually form another jungle, and many hundreds of feet above the buried coal bed *b* a second bed of peat and vegetable matter would begin to accumulate to form the coal bed *a*.

Such is the history of how the coal which we now dig out of the depths of the earth once grew as beautiful plants on the surface. We cannot tell exactly all the ground over which these forests grew in England, because some of the coal they made has been carried away since by rivers and cut down by the waves of the sea; but we *can* say that wherever there is coal now, there they must have been.

Try and picture to yourselves that in the western part of Pennsylvania, where all is now black with coal dust, and grimy with the smoke of furnaces, and where the noise of hammers and steam engines and of carts and trucks hurrying to and fro makes the country reecho with the sound of labor, there ages ago, in the silent swamp shaded with monster trees, one thin layer of plants after another was formed, year after year, to become the coal we now value so much. In Michigan the same thing was happening, and even in the middle of Illinois and Iowa the sea must have come up and washed silent shores where vast forests spread out over hundreds of square miles. In Wyoming, too, which is now almost the middle of the Rockies,

another small coal field tells the same story, while in West Virginia the deep coal mines and number of coal seams remind us how for centuries and centuries forests must have flourished and have disappeared over and over again under the sand of the sea.

But what is it that has changed these beds of dead plants into hard, stony coal? In the first place you must remember they have been pressed down under an enormous weight of rocks above them. We can learn something about this even from our common lead pencils. At one time the *graphite*, or pure carbon of which the blacklead (as we wrongly call it) of our pencils is made, was dug solid out of the earth. But so much has now been used that they are obliged to collect the graphite dust and press it under a heavy weight, and this makes such solid pieces that they can cut them into leads for ordinary cedar pencils.

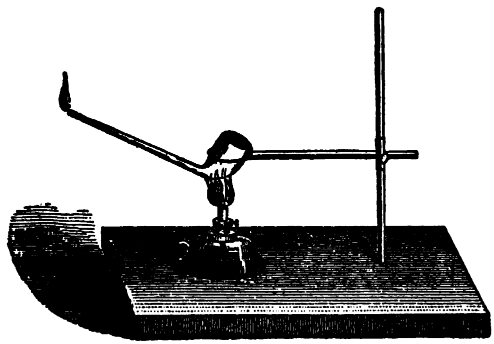
Now the pressure which we can exert by machinery is absolutely nothing compared to the weight of all those hundreds of feet of solid rock which lie over the coal beds, and which has pressed them down for thousands and perhaps millions of years; and besides this we know that parts of the inside of the earth are very hot, and many of the rocks in which coal is found are altered by heat. So we can picture to our-

selves that the coal was not only squeezed into a solid mass, but often much of the oil and gas which were in the leaves of the plants was driven out by heat, and the whole baked, as it were, into one substance. The difference between coal which flames and coal which burns only with a red heat is chiefly that one has been baked and crushed more than the other. Coal which flames has still got in it the tar and the gas and the oils which the plant stored up in its leaves, and these when they escape again give back the sunbeams in a bright flame. The hard stone coal, on the contrary, has lost a great part of these oils, and only carbon remains, which seizes hold of the oxygen of the air and burns without flame. Coke is pure carbon, which we make artificially by driving out the oils and gases from coal, and the gas we burn is part of what is driven out.

We can easily make coal gas here in this room. I have a tobacco pipe, the bowl of which is filled with a little powdered coal, and the broad end cemented up with clay. When we place this bowl over a spirit-lamp and make it very hot, the gas is driven out at the narrow end of the pipe and lights easily (see Fig. 9). This is the way all our gas is made, only that furnaces are used to bake the coal in, and the gas is passed into large reservoirs till it is wanted for use.

You will find it difficult at first to understand how coal can be so full of oil and tar and gases until you have tried to think over how much of all these there is in plants, and especially in seeds—think of the oils of almonds, of lavender, of cloves, and of caraways; and the oils of turpentine which we get from the pines, and out

Fig. 9.



of which tar is made. When you remember these and many more, and also how the seeds of the club moss now are largely charged with oil, you will easily imagine that the large masses of coal plants which have been pressed together and broken and crushed would give out a great deal of oil which, when made very hot, rises up as gas. You may often yourself see tar oozing out of the lumps of coal in a fire, and making little black bubbles which burst and burn. It

is from this tar that James Young first made the paraffin oil we burn in our lamps, and the spirit benzoline comes from the same source.

From benzoline, again, we get a liquid called analine, from which are made so many of our beautiful dyes—mauve, magenta, and violet; and, what is still more curious, the bitter almonds, pear drops, and many other sweets which children like so well, are actually flavored by essences which come out of coal tar. Thus from coal we get not only nearly all our heat and our light, but beautiful colors and pleasant flavors. We spoke just now of the plants of the coal as being without beautiful flowers, and yet we see that long, long after their death they give us lovely colors and tints as beautiful as any in flower world now.

Think, then, how much we owe to these plants which lived and died so long ago! If they had been able to reason perhaps they might have said that they did not seem of much use in the world. They had no pretty flowers, and there was no one to admire their beautiful green foliage except a few croaking reptiles and little crickets and grasshoppers; and they lived and died all on one spot, generation after generation, without seeming to do much good to anything or anybody. Then they were covered up and put out of sight, and down in the dark

earth they were pressed all out of shape and lost their beauty and became only black, hard coal. There they lay for centuries and centuries, and thousands and thousands of years, and still no one seemed to want them.

At last, one day, long, long after man had been living on the earth, and had been burning wood for fires, and so gradually using up the trees in the forests, it was discovered that this black stone would burn, and from that time coal has been becoming every day more and more useful. Without it not only should we have been without warmth in our houses, or light in our streets when the stock of forest wood was used up; but we could never have melted large quantities of iron ore and extracted the iron. We have proof of this in Sussex, England. The whole country is full of iron ore, and the railings of St. Paul's churchyard are made of Sussex iron. Iron foundries were at work there as long as there was wood enough to supply them, but gradually the works fell into disuse, and the last furnace was put out in the year 1809. So now, because there is no coal in Sussex, the iron lies idle; while in the north, where the iron ore is near the coal mines, hundreds of tons are melted out every day.

Again, without coal we could have no engines of any kind, and consequently no large manu-

factories of cotton goods, linen goods, or cutlery. In fact, almost everything we use could only have been made with difficulty and in small quantities; and even if we could have made them it would have been impossible to have sent them so quickly all over the world without coal, for we could have had no railways or steamships, but must have carried all goods along canals and by slow sailing vessels. We ourselves must have taken days to perform journeys now made in a few hours.

In consequence of this we should have remained a very poor people. Without manufactories and industries we should have had to live chiefly by tilling the ground, and everyone being obliged to toil for his daily bread, there would have been much less time or opportunity to study science, or literature, or history, or to provide the comforts and refinements of life.

All this, then, those plants and trees of the far-off ages, which seemed to lead such useless lives, have done and are doing for us. There are many people in the world who complain that life is dull, that they do not see the use of it, and that there seems no work specially for them to do. I would advise such people, whether they are grown up or little children, to read the story of the plants which form the coal. These saw no results during their own short existences;

they only lived and enjoyed the bright sunshine, and did their work, and were content. And now thousands, probably millions, of years after they lived and died, England owes her greatness, and we much of our happiness and comfort, to the sunbeams which those plants wove into their lives.

They burst forth again in our fires, in our brilliant lights, and in our engines, and do the greater part of our work; teaching us

> "That nothing walks with aimless feet,
> That not one life shall be destroyed,
> Or cast as rubbish to the void,
> When God hath made the pile complete."
>
> —*In Memoriam.*

IV

Useful Bacteria

By C. B. ATWELL, Ph.B., Professor of Botany, Northwestern University

THIS is an old topic, and my story is an old story. Since the year 1675, when Anthony van Leeuwenhœk, a Dutch lens maker, discovered in various putrefying materials minute living and moving forms, scientific men have been accumulating facts concerning bacteria. The history of the growth of our knowledge of this group of organisms, through more than two centuries of persistent investigation and critical discussion, has been of intense interest both to the scientific and the unscientific world. The search for the truth concerning bacteria led to the announcement of the germ theory of putrefaction and fermentation as early as 1720; it brought forth the germ theory of the origin of disease so well known at the present time; and it was the occasion for setting forth the theory of spontaneous generation in 1749, which was overthrown a century later (1854) by the successful experimentation of Schroeder and Von Dusch. The triumphs of modern surgery, the successful checking of the spread of disease by means of preventive inoculation, the great ad-

vance of hygiene in relation to infective disease, the modern industry of preserving meats, fruits, and vegetables by boiling them and then sealing them from the atmosphere, are all to be credited to the outgrowth of the investigation of bacteria.

So extensive has been the interest in bacteria as related to *disease* that the general opinion prevails that they are chiefly disease-producing organisms, and the long list of diseases now credited to them goes to confirm this opinion. We hold bacteria responsible for cholera, diphtheria, pneumonia, influenza, leprosy, relapsing fever, lockjaw, typhoid fever, and consumption. Says Professor Cohn, in his little book on the *Story of Germ Life:* "Perhaps the most universally known fact in regard to bacteria is that they are the cause of disease. It is this fact that has made them subjects of such wide interest. This is the side of the subject which first attracted attention, has been most studied, and in regard to which there has been the greatest accumulation of evidence. So persistently has the relation of bacteria to disease been discussed and emphasized that the majority of readers are hardly able to disassociate the two. To most people the very word *bacteria* is almost equivalent to disease." Indeed, so much has been said and written about their harmful characteristics that it ought not to be considered strange

that we have come to overlook the fact that, taking all things into account, bacteria are not so much harmful as helpful to mankind. I desire to bring before you some facts which will, I hope, tend to remove this prejudice against bacteria, and will go to show to what extent humanity is debtor to bacteria as agents of good.

The better to understand our discussion let us ask, What are bacteria?

They are the smallest and at the same time the most ubiquitous organisms known to man. Because of their minuteness great difficulties attended the early attempts to investigate them, nor have all these difficulties been removed; but after two hundred and twenty-five years of investigation very simple methods have at last been developed whereby the more common forms may be investigated easily and with accuracy.

We now know that bacteria are plants, very simple in their structure and growth; in fact the simplest of all organisms. They are distributed all over the world wherever there is moisture, warmth, and food supply. No other organisms are distributed so universally. They are in the air, the water, the soil. Soil bacteria are found usually at or near the surface. Water bacteria are found in all waters exposed to the air or to

drainage of soils both at the surface of the water and throughout its depths, and upon its bottom. Air bacteria are most numerous in habitated regions, and especially near and upon the surface of the ground. They are in excessive abundance in all decaying matter—in manure piles, in dead bodies of plants and animals, in all filth and slime. They are abundant in the cavities of the mouth, stomach, and intestines of all animal life, including man. They do not, however, occur in the healthy tissues of living animals or plants. They are found in great quantities upon the surface of our bodies, under the finger nails, in every wrinkle and crevice of the skin, in the hair, and in all secretions from the body. Flies carry them on their feet and bees among their hairs. The raindrops and snowflakes sweep them from the sky.

The ordinary bacteria consists of a single cell. Twenty-five thousand placed side by side would make a chain or ribbon only one inch in length. Although millions of bacteria are found in air, soil, water, and organized matter, yet only three different shapes prevail among them. These are known as the *coccus*, the *bacillus*, and the *spirillum*. The word coccus is applied to spherical forms, bacillus is used for cylindrical forms varying somewhat among themselves in length, while spirillum applies to those having a spiral

shape, often similar to a corkscrew. Each of these forms is a single cell or a small series of similar cells.

Now each cell must be thought of as a minute portion of living protoplasm incased in a thin wall or covering of its own manufacture. This protoplasm is the same as that of other plants and that of animals. It performs all the functions of life. It is the source of every activity manifested by the bacterium. Each cell absorbs food, becomes distended and enlarged. It then proceeds to divide its contents into two parts by means of a partition wall which it constructs across the middle of the cell, and thus it becomes two cells. This process may, under favorable circumstances, take place as often as once an hour. If the proper food supply could be provided and controlled, so that in growing no cell would interfere with another, but all alike should have free access to food, one cell would in three days (according to Cohn) become four thousand seven hundred and seventy-two billions of bacteria and would weigh seventy-five hundred tons! This, however, is prevented by interference of the cells with one another, and thus nature protects herself.

The specific differences between two bacteria lie not so much in their form as in their physiological activity. Thus, of two bacteria living

side by side, having the same appearance and measurements, one might be able to flourish in water while the other would grow naturally only upon salt fish. If cultivated artificially the first might produce a beautiful, glistening, white, radiating colony when grown on moist gelatine, while the other would dissolve the gelatine, leaving a yellow granular deposit at the bottom. Thus it would be clear that they were very different in character though not in form.

As to the character of the food supply, two facts are to be considered. Bacteria are either parasites or saprophytes. By parasites we mean those which invade and feed upon living plants or animals. Thus the bacteria of consumption, which feed upon living lung tissue, are parasites. By saprophytes we mean those which find their living in or upon dead vegetable or animal matter. It is of this group we shall have most to say. Yeast, which is a plant germ closely related to bacteria, is a saprophyte, because it feeds upon the dead flour-starch and sugar found in the bread sponge.

We note also that bacteria are destructive rather than constructive, which is a peculiarity unlike most plants. If we consider the growth of a green plant from the sprouting of the seed until the fruit is formed, as for example an oak tree, we recognize that throughout its whole

history it has accumulated material from outside sources; it has grown larger and heavier; it has taken up the simplest compounds found in the soil and air and, converting them into the more elaborate compounds of plant substance, has stored them in the plant itself or its fruit, thus adding to the organic matter of the earth's surface. Not so with bacteria. They tear down the complex structures of plant and animal substance and break them up into simpler compounds. So we say the life of bacteria is destructive while that of green plants is constructive.

Let us consider next how the scientist is able to seize, control, and cultivate these extremely minute, prolific, and omnipresent organisms. Briefly, avoiding technicalities, it is about as follows:

1. Lean, raw beefsteak is freed from all fat and chopped fine; then soaked overnight in cold water; the fluid is drained off and is boiled; gelatine of the highest grade is added and certain quantities of common salt, soda, and a liberal supply of albumen peptone. The mass is now strained and filtered and allowed to cool, when it is found to be a clear, amber-colored jelly. This is the cultivating medium or soil upon which most bacteria will grow luxuriantly.

2. Glass flasks, tubes, and flat dishes are ster-

ilized by heating them in a closed oven until the cotton plugs which have been placed in the mouths of the flasks and tubes are slightly scorched. This requires a temperature of 160 degrees C., which is hot enough to destroy all bacteria which may be clinging to their surfaces.

3. The next day the meat gelatine is heated and a small supply poured carefully into each flask and tube; these are sterilized in a steam bath the following day to kill off any bacteria which may have fallen into the gelatine in the process of pouring. We now have small supplies of gelatine in closed vessels and upon this gelatine we can cultivate our bacteria.

Suppose a drop of water to be placed upon a prepared surface of gelatine. It will spread out and sink into the gelatine leaving upon the surface the invisible but ever-present bacteria. These will absorb food from the gelatine and grow rapidly. In twenty-four to thirty-six hours so many bacteria will have developed that the spots or colonies will be visible to the unaided eye. From any one of the many colonies which develop in this manner out of a drop of water transfers may be made to separate dishes, and thus pure cultures or growths of a chosen bacterium may be obtained.

Having thus obtained a pure culture the experimenter is easily able to ascertain upon what

foods it will flourish most luxuriantly; what may be its most favorable temperature; whether it produces poisons; what effect it may have if inoculated into living plants or animals. In fact he comes by repeated experiments to know the whole life of any bacterium which he may select to study. It is much in this way that we have learned which bacteria are harmful and which are helpful to man.

We should regard the bacteria of air and water as, with occasional exceptions, our friends. This is because they are putrefactive bacteria. Kerner puts it, "Putrefactive bacteria are the best purifiers." Suppose we leave an apple upon the ground in the orchard. We soon discover it is soft and rotten. If undisturbed it gives off an unpleasant odor, it flattens out into a watery mass, and will finally disappear by evaporation and absorption by the soil. This is an example of complete putrefaction. A tree in the forest falls to the earth. Does it always remain there clogging the path? The rains fall upon it bringing bacteria from the air, others come from the soil. Every crevice and soft spot is attacked; the cells and passageways which were once full of sap and plant substance are now filled with bacteria which seize upon every particle of matter living and dead. The tree soon becomes rotten and soft and is the

prey of every storm. In time it will disappear. All the tons of materials which were centuries perhaps in accumulating have returned to air and soil.

So it is with the dead bodies of animals, only the decomposition is more rapid and the escaping gases more abundant and more disagreeable. So also with the sewerage of our cities. The putrefactive bacteria attack it and tear it to pieces, consuming a portion in order to construct new bacteria, but setting free the unused substances in such changed and simplified forms that they return to nature and are harmless to us.

It is clear, therefore, that the putrefactive bacteria of the soil and atmosphere are devoted to decomposition and distribution. Suppose there were no such provision in nature. All the earth would become one vast graveyard! Plant life, the grains, grasses, fruits, and vegetables would exhaust the soils. The animal life would consume the plant life, and, death following without putrefaction, no restoration to the soil would occur. The surface of the earth would be covered and cumbered with the dead! Thus we see there is absolute necessity for the death of animals and plants and for their disintegration and the distribution of their substance into the atmosphere and the soil if life is to be

continued. Putrefactive bacteria are the agents provided in nature to bring this to pass.

We hear a good deal about bacteria in our water supply, and it is proper that we should be warned of their superabundance and should guard ourselves against consuming too many of them in our drinking water, lest we disturb our ordinary digestive operations or admit disease-producing bacteria to our system.

But why are the bacteria in the water? Is it not because of the organic matter suspended in the water from our sewers or washed from the soil? What are they doing? They are doing their very best to disintegrate this foul organic stuff and change it into innocent and harmless forms. Indeed, if we could allow the water to remain quiet, as in a pond, for a few days and give the bacteria a chance, all harmful substances would be eliminated by the bacteria themselves. If no new supplies were sent in the water would thus become pure drinking water. The harm to us arises in drinking the water before the organic material has been reduced. The bacteria are then so numerous and their food supply so abundant that they are likely to do harm to us, and bacteria of disease may also be present.

All ordinary water, whether from the lake, river, spring, or well, contains bacteria. When

the number does not exceed one thousand to the cubic centimeter (two thousand to a small thimbleful) it is considered to be good drinking water. We have been drinking water of that character all our days. It would be a surprise to our stomachs if we omitted the bacteria. The city of Paris pours the sewerage from more than two and a half millions of people into the river Seine. The putrefactive bacteria attack this sewerage, and thirty-five miles below Paris the water of the river is again pure. What has become of the sewerage? The result of the work of putrefactive bacteria in general is that the face of the earth is kept clean, old matter becomes new, life repeats itself, and we live.

In the soil bacteria are numerous, especially in the dark fertile layers near the surface. These bacteria seize upon the food materials passed into the soil as waste products of the putrefactive bacteria. Some of these food materials are in a form easily used by green plants; but other forms, especially those containing nitrogen, must be further worked over before the higher plants can take them in. The chemist tells us all they need is an addition of oxygen. In other words, some nitrogen products of putrefaction are too simple for the use of ordinary plants. The addition of oxygen is accomplished by a process made known to us within a few

years, and the work is done by a group of bacteria known as nitrifying bacteria. There are several kinds, each having different powers. After their work is done all that is left of the decomposition products is capable of being seized upon by the rootlets of plants and converted into plant substance, and thus it may become our daily food in the corn, wheat, and vegetables raised upon the soil.

One important group of soil bacteria remains to be noticed in this connection. Observers have found that in plants of the pea family, such as peas, beans, and clovers, nitrogen accumulates to an extent beyond what can be accounted for in the food supply found in the soil. Even if all nitrogenous food supply be cut off from them, still these plants are able to obtain nitrogen from some source. Investigations of late years reveal the fact that this is brought about by bacteria in the soil which break through the tender cells of the young roots of the plants and construct a dwelling place therein, a sort of "tubercle" in which they live. This living within the anatomy of the higher plant does not prove detrimental to either party concerned. On the contrary the arrangement is mutually helpful. The bacteria have a little hut which they call their own, a workshop wherein they proceed to construct, in some strange way,

food stuffs for their host plants out of the nitrogen gas of the atmosphere and the solutions absorbed from the soil. This new food is assimilated by the host plants and stored in their fruits. Thus peas and beans are rich in nitrogen because of the supplies obtained from the atmosphere by these soil bacteria. Further than that, the soil in which such plants grow is found to be richer in nitrogenous food supplies after a crop of these plants has been removed than before they were planted. This is due to the fact that the bacteria at work in the roots accumulate a surplus supply of nitrogen taken from the atmosphere, and when the stems of the plants die or are cut off these materials are left for the enrichment of the soil.

These soil bacteria have been systematically investigated by experts both in America and Europe. Our government maintains fifty-two experiment stations for work upon agricultural problems, and in several of the stations bacteriological investigations are going on. A late bulletin from the United States Agricultural Department announces that German investigators have been successful in the development of pure cultures of these bacteria on a commercial scale protected by letters patent, so that farmers can now purchase these patented bacteria, and stock sterile soils for special crops, at a cost of

\$1.25 an acre. Thus we see that these bacteria are so useful that they are likely to affect the market value of farm produce.

Let us turn to another side of our subject. We have long known that danger lurks in milk because of the possibility of the presence of disease-producing bacteria which are likely to find an abiding place in it. If we bring the milk to a boiling temperature we kill these disease germs and remove the danger. There are other bacteria in the milk which bring about various fermentations, and which we may regard as enemies, but to the butter-maker bacteria in milk prove to be the best of friends.

It is customary to allow cream to sour or ripen before churning. At this time butter bacteria are multiplying rapidly and setting up fermentation in the cream. A warm temperature hastens the process and promotes the ripening of the cream. Now cream ripened in this manner produces more butter with a fine flavor or aroma than when made by sweet cream or by any other process. We all know how desirable it is that table butter should have a pleasant flavor; it is that which makes it palatable and gives it market value. This flavor is undoubtedly due to the growth of the bacteria in the cream. The volatile acids which give the flavor are not present in fresh milk, and only appear

after the bacteria have been at work. A Swedish scientist (Storch) assumed that this flavor was due to the work of organisms, and made a careful study of the subject with the view of proving or disproving his assumption. He succeeded in obtaining pure cultures of bacteria which produced the delicate flavor when used to ripen cream. Others have confirmed his work, and now these pure, artificial cultures are used in creameries of Germany—insuring to a certainty the quality and market value of the butter so treated. American workers in a Connecticut experiment station developed cultures of bacteria found in milk sent to the Columbian Exposition, and artificial cultures of the same are now sent out from various laboratories to butter makers in several Eastern States, with which cream is inoculated and the best of flavors obtained. When butter made by this process appears upon our tables we pronounce it excellent, and we should be thankful for the bacteria which contributed to that result. Undoubtedly bacteria have always performed this function in butter making.

In the making of cheese bacteria are absolute necessities. The proper flavor can only be obtained by a ripening process of weeks and months. This has been conclusively demon-

strated to be due to a bacterial growth and activity. If the bacteria are killed off in the fresh cheese the cheese will not ripen. The cheese maker, by using bacterial cultures, may always control the quality of his product, and this he has done for hundreds of years.

We are all familiar with the use of yeast, especially in the making of bread. Yeast and bacteria are closely related in the same general group of plants and are often found working together. It would not be improper to regard yeast as the most useful of the bacterial group of organisms. In the making of vinegar from cider we see how yeast and bacteria work together. If fresh apple juice or sweet cider be allowed to stand for some time in contact with the air it will slowly become alcoholic or "hard." This change is brought about by the work of yeast, which enters the cider from the air and feeds upon the sugar found in the apple juice. This leads to the decomposition or breaking up of the sugar; a portion entering the cider in the form of alcohol, another portion escaping to the air in the form of bubbles of carbonic acid gas. We say, "The cider is fermenting; it will soon become hard cider." When all the sugar has been acted upon by the yeast the process of alcoholic fermentation ceases, and soon we find another process has begun. This time the

workers are bacteria, entering the cider from the air as did the yeast. These bacteria feed upon the alcohol and split it up, forming acetic acid in the cider, which we now call cider vinegar. The process of making acetic acid out of alcohol consists simply in adding two atoms of oxygen from the air to each molecule of alcohol. This chemical change can be performed in the laboratory experimentally, but it is not practicable on a large scale, so we shall continue to depend upon yeast and bacteria for our pure cider vinegar, as we have done in all past history.

Let us inquire next about bread making. Surely if bacteria have anything to do in this we are interested to know about it. Many investigators have worked upon the problem involved in the fermentation of bread. In one article published in the *Botanical Gazette* of 1890 I find a list of ten scientific researches upon this subject. Four maintain that the fermentation is wholly due to the work of bacteria; or, at most, yeast is only a secondary agent. Three claim that yeast does all the work and the bacteria present (and they are always present) are to be regarded as a pollution. The remaining three hold that both the yeast and the bacteria are necessary to produce the proper results. This was prior to 1890. Then came an eleventh in-

vestigator, with the best of modern appliances and under the best of supervision. This was Miss Katherine E. Golden, of Purdue University. Her work was devoted to bread raised from compressed yeast. She always found the common yeast and common bacteria present. She separated these and developed pure cultures of each in considerable quantities and kept them growing for two and one half months. Then they were tested to see which would produce the more carbonic acid gas, the gas developed in the fermentation. The yeast gave off twenty-three milligrams in one hour, and the bacteria seventy milligrams in the same time under the same conditions. A second series of tests were made from cultures four days old, when the yeast gave fifty milligrams and the bacteria sixty milligrams. Bread sponge was made from each of these cultures, and the dough kneaded thoroughly and allowed to "rise" twenty-four hours in a sterilized chamber; then followed a second kneading. The yeast dough rose higher than the bacterial dough in each case, but it lacked the tough, elastic qualities of good bread. The bacterial dough felt like ordinary dough, being more elastic and tougher, and having a sweeter odor than did the yeast dough.

After baking, the yeast bread in every case showed the greater degree of lightness, but was

coarse in texture, being filled with numerous large cavities. The bacterial bread, though apparently not so well risen, had a finer texture with occasional large cavities. The investigator reached the opinion that yeast and bacteria are each capable of making good bread, but the only satisfactory conclusion is that they act together in the raising of most if not all kinds of bread. We are able to make no raised bread without both being present.

There are still other examples of useful bacteria which may be brought to notice briefly.

Bacteria perform a very necessary work in the process of "retting" flax in the linen industry, without which we would not have our fine linens and delicate laces. Bacteria perform a similar work in the treatment of jute, hemp, and cocoa fibers, from which we get our best cords, ropes, and mattings. In the American process of tanning leather bacteria are found necessary, and so also in the preparation of citric, acetic, lactic, and butyric acids. Indigo prepared for the market is a product of bacterial fermentation. Bacterial fermentations play a prominent part in the curing of tobacco. Sometimes the leaves are directly inoculated with fermenting material, and especially is this useful in the manufacture of snuff. Special flavors and aromas of tobacco are produced by various fermentations.

Useful Bacteria

One form of bacteria may be made useful in destroying another or in destroying vermin and other pests. Field mice increase very rapidly, and often cause great destruction and loss to the crops. A French scientist, Dr. Danysz, now claims that they can be easily and very cheaply exterminated by bacteria cultivated for that purpose. He chose a tract of about one hundred and eighty-five acres, where he calculated from the number of burrows that there were five to ten thousand of the pests to the acre. Having dissolved cultures of the bacteria in water, he soaked in the fluid small bits of bread, which he scattered over the field. Toward the third day after the distribution sick mice were found over the field so treated. Two weeks afterward, in a field of clover, there were found only three mice, and these already sick unto death, while in a neighboring field, that had not been treated, fifty living mice were found in every burrow.

The sprouting of seeds is promoted by bacteria, and the control and management of the silo, by which the farmer preserves fresh vegetable food for his cattle in their winter quarters, depends upon the activity of common bacteria.

Even the first formation of soil from rocks is due in part to the work of bacteria, which are able to secrete acids to soften the rocks, and

thus open the way to weathering and disintegration and the formation of elementary soil.

To conclude: Since bacteria clear our streams and lakes of sewage and strive to make all waters pure; since they decompose dead animals and plants, and turn them into the dust from which they came; since they nitrify sterile soils from the vast supply of nitrogen in the atmosphere, thus preventing exhaustion of soils and assuring us of a continued supply of fruits, vegetables, and the grains; since the very bread we eat and the butter and cheese that go with it are made palatable by them; and since they enter so directly and usefully into so many of the industries of daily life, ought we not to regard them as helpful to humanity rather than harmful?

V

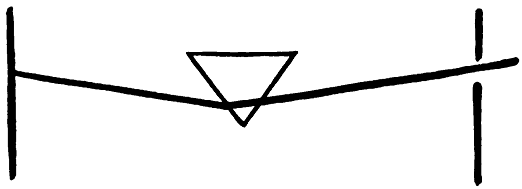
The Story of the Spectrum

Adapted from *The Sun*, by C. A. YOUNG, and *Popular Astronomy*, by J. N. LOCKYER

SHOULD a traveler come into our homes from some far distant land, we would with eagerness listen to his tales of the things he had seen; the conditions, the occurrences, and the history of the places he had visited; and the farther his travels had extended the greater would be our interest in his narrative. How earnest, then, should be our attention when the little sunbeam, after a journey of ninety-three millions of miles, unfolds its mysteries of color and proceeds to tell us the story of its source. It is within the past forty years that the secret of the solar spectrum has been revealed by such men as Sir John Herschel, Foucault, Fraunhofer, Kirchoff, and Bunsen. Their united efforts have unfolded in the sunlight a wondrous tale. That those tiny rays move the winds, and stir the deep, and lift the seas in clouds to hurl them on the mountain tops, or, stored in long-buried marshes, come forth to light our darkest nights or move our mightiest machines, is marvel enough for most reasoning minds. That they, besides doing all the world's work, furnish its beauty as well in

the varied tints and colors that gladden the eye and enliven the earth, is cause for the observer's admiration. But that, in addition, they carry a message of the elements composing the sun, of the condition of those elements and of their motion, seems a vision of the imagination and not a conclusion based upon reason and investigation. The study of the spectra has opened a new world of research to physics and

Fig. 1.



chemistry, such as the telescope brought to our vision.

An extended discussion of the instruments, principles, and methods of spectroscopy is impossible in a popular article. A brief view of each of these three divisions of the subject must suffice. First, the instruments. A triangular prism, placed in a ray of red light admitted through a narrow slit in the window blind, will produce on the opposite wall an image of the slit of the same color as the light admitted (Fig. 1).

If, instead of a slit the opening had some other

form, as an arc of a circle, a triangle, or a square, the image seen would imitate it, always having the same color as the light admitted. Suppose, again, that the light is not a single color, but consists of two kinds mixed together—say red and yellow (Fig. 2). Viewing the slit directly, without a prism, one would see only a *single*

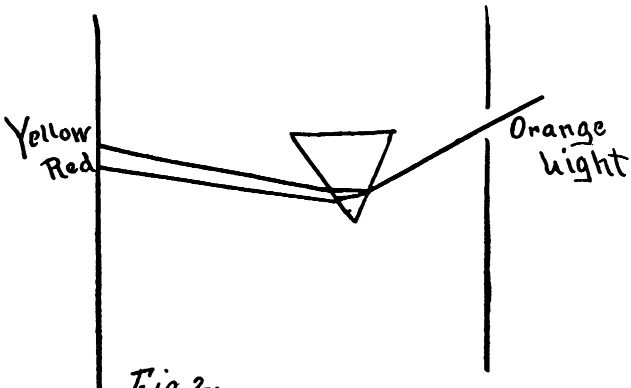


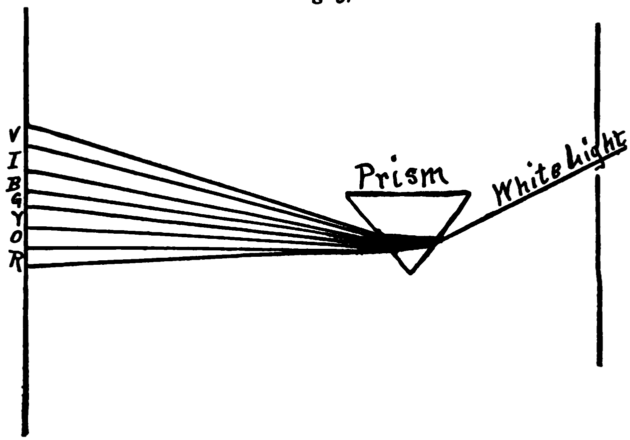
Fig. 2.

orange-colored image, but with the prism one would see *two* widely-separated images, one of them red, the other yellow. This is because the prism refracts the two kinds of light differently, so that after the rays have passed the prism they take different directions, and then make images in different places.

If the light is composed not of two kinds only, but of many, the images will be numerous,

ranged side by side like the pickets of a fence; and if, as in the case of the candle flame, the light emitted contains an indefinite number of tints, then the slit images, placed side by side, will unite into a continuous band of color. This is called the spectrum, and its colors are ar-

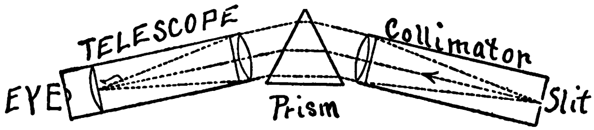
Fig. 3,



ranged in the following order: Violet, indigo, blue, green, yellow, orange, red (Fig. 3). If in the candle light certain kinds of light are specially abundant, then the corresponding slit images will be more brilliant than their neighbors; and if, as is usually the case, the slit be narrowed to a line, these slit images will become bright lines in the spectrum—lines only because the slit is itself a line. This, of course, is the

best form to give the opening, in order that the different images may overlap and interfere as little as possible. If any kinds of light be wanting, then the corresponding images of the slit will be missing, and the spectrum will be marked by dark bands or lines. It is often desirable to obtain a greater separation of the different colors—"dispersion," to use the technical term—than a single prism would produce. In this case the rays are aimed at the prism through a tube bearing a lens at one end; this is called the collimator (Fig. 4). After passing through

Fig. 4.



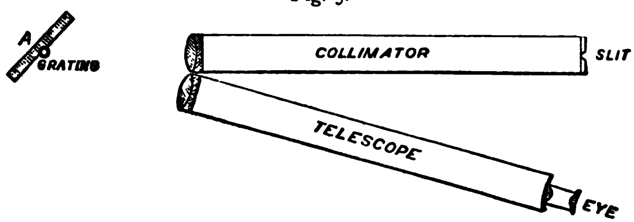
— PLAN OF A SPECTROSCOPE.

the first prism the rays may be transmitted through a second and a third, and so on until they reach a small telescope, which magnifies from five to twenty times.

Another way is to use a diffraction grating in place of the prism. This diffraction grating is merely a series of close, equidistant, parallel lines ruled upon a plate of glass or polished metal. The diffraction grating has almost replaced the prism in the spectroscope of to-day

(Fig. 5). It is to be remembered, however, that the real work of the spectroscope is done by the slit and the prism, and that the collimator and the view telescope are not essential, but are simply appliances to secure a larger and more convenient spectrum. Fraunhofer, who first discovered the clear, sharp lines in the rainbow-tinted band of the sun's spectrum, did all his work with the light admitted through a slit

Fig. 5.

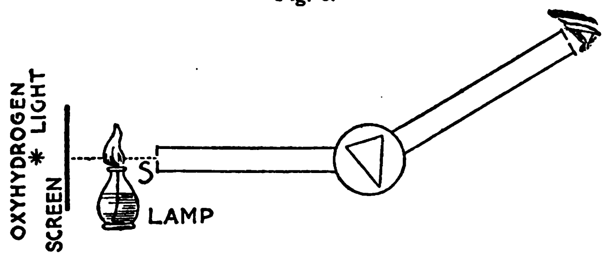


in the window blind at a distance of twenty or thirty feet.

If the spectroscope be turned toward an ordinary lamp or the incandescent lime of the calcium light, the observer will get simply a continuous spectrum—a band of color without lines of any kind and shading gradually from red to violet. If, instead of using the lamp flame or the calcium light, we examine with the spectroscope the electric spark, or the space between the carbon points of the arc light, we shall get a spectrum of quite a different sort—a spec-

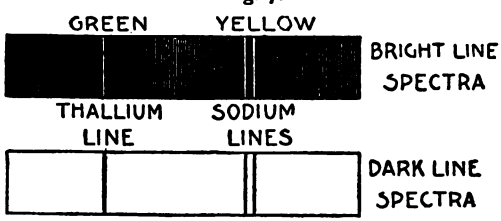
trum consisting of bright lines on a darker background. These lines will be invariable under the same circumstances. If now we combine these two sources of light, and cause the light

Fig. 6.



of the hot solids in the lamp or the lime light to shine through the luminous gas into the spectroscope, there appears a remarkable result (Fig. 6). The band of colors given by the solids is now

Fig. 7.



crossed by hundreds of fine dark lines, and, what is still more remarkable, these dark lines are just where the bright lines were in the spectrum of the luminous gases (Fig. 7). Now, turning

the spectroscope toward the sun, we find a spectrum similar to that last described—a bright band of color crossed by thousands of dark lines (Fig. 8).

These experiments which we have been imagining were all performed and described by Kirchhoff about forty years ago; and these

Fig. 8.

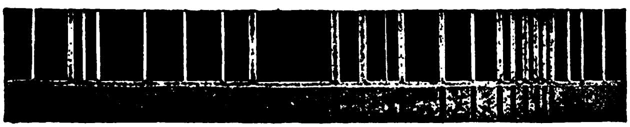
same results have since been observed by thousands of students in this field of science.

These three kinds of spectra—the continuous formed by the lamp or calcium light; the bright line, formed by incandescent gases; and the discontinuous, formed by the combination of both, and also produced by the sun—furnish a key to the story of the spectrum.

Let us sum up, as briefly as possible, the results of these investigations. First, white-hot, incandescent solids and liquids give continuous

spectra—that is, a band of graded colors. Second, incandescent gases give bright line spectra of different colors. Third, gases absorb from the white light of similar solids the bright lines which they themselves produced, giving a discontinuous spectrum—that is, a band of color crossed by dark lines. These three principles fully account for the discontinuous spectrum of the sun and the multitude of Fraunhofer lines which cross it. They also clearly indicate how to ascertain the elements composing the sun.

Fig. 9.



The process is one of mapping or photographing the solar spectrum and alongside of it the spectra of terrestrial elements whose existence in the sun is suspected. Fig. 9 shows a comparative map of this sort.

In this way about forty elements found on the earth have been identified in the sun. The certainty with which an element is recognized depends on two things: the number of coincidences of spectral lines and the intensity of the lines. Calcium, or lime, ranks first in intensity, but iron has by far the greatest number of lines,

with more than two thousand coincidences. Iron, calcium, hydrogen, nickel, and sodium are the most strongly indicated. Chlorine and nitrogen, abundant elements on the earth, and gold, mercury, phosphorus, and sulphur are not indicated in the solar spectrum. Helium, first found in the sun with the spectroscope, has since been discovered on the earth in minute quantities; still another element shown in the solar spectrum, and named coronium, remains to be found in the earth.

Is not this, indeed, a marvelous tale brought by the sunbeam? It says, "Where I came from there exist many of the same elements found in the earth. There they glow with the fervent heat which started me on my journey. From a white-hot, molten mass, I passed through a thousand miles of gases, containing the metals I had left behind, on through other clouds of light, then through millions on millions of miles of space, till here my journey ends and my labors begin. And it is less than nine minutes since I started."

But does the story end here? We can read still another chapter, and possibly there are others yet to be translated. This chapter relates to the motion of the luminous matter in the sun, and is told, as before, by the little lines in the spectrum.

Did you ever hear a train whistle as it came rapidly toward you, and notice that the pitch ascended; and if it whistled again when receding, did you notice that the cadence was downward? The reason is that, as the train approaches more sound waves strike the ear in a second, making a higher pitch, and when it is receding, fewer in a second, making a lower pitch. Now, light, like sound, is transmitted in waves, and the greater the number of waves per second which strikes the prism or grating of the spectroscope the further the ray is bent. The application of this principle, known as Doppler's principle, is very simply explained in Professor Todd's *New Astronomy:*

"From a bridge spanning a rivulet, whose current is uniform, we observe chips floating by, one every fifteen seconds. Ascending the stream, we find the origin—an arithmetical youth on the bank has been throwing them into the midstream at regular intervals, four chips a minute. We interfere with his program only by asking him first to walk down the stream for two minutes, then to return at the same uniform speed; and to repeat the process several times, always taking care to throw the chips at precisely the same intervals of fifteen seconds, as at first. Returning to the bridge to observe, we find the chips no longer pass at intervals of

fifteen seconds, as at first, but that the interval is less than this amount while the boy is walking down stream, and greater by a corresponding amount when he is going in the opposite direction. By observing the deviation from fifteen seconds, the speed at which he walks can be found.

"Similarly with bodies in the sun when moving toward or from the earth; the boy is the moving body, and the chips are the crests of light waves coming from it. When the body is coming nearer more than the normal number of waves reach us in a second, and a given line in the spectrum is displaced toward the violet. Likewise, when the luminous body recedes, the same line deviates toward the red.

"Now, this distortion seldom occurs in the sun's spectrum, but occasionally it happens that there is violent motion, either toward or from us, of the gases above a spot; this produces in the spectrum a marked distortion or branching of the dark lines. By measuring the amount and direction of this distortion it can be calculated whether the gases were rushing toward or from us, and at what speed. On rare occasions these velocities have been as great as two hundred or even three hundred miles per second."

In telescopic work the spectroscope is attached to the eye-end of a large telescope, the eyepiece

being removed. The instrument is then often called a telespectroscope. If this instrument is now turned upon a star, the same facts may be deduced from its spectrum as were shown in the study of the sun. Many stars have been found to contain nearly the same elements, and in the same condition, as those of our sun. Others, more numerous, have been found giving evidence of the presence of hydrogen, iron, calcium, and sodium. The direction in which these stars are moving and their velocity have also been computed in many cases. More than ten thousand have been classified and catalogued. Research of this character is an important part of the program at Greenwich and at the Yerkes Observatory.

All in all, no discoveries during this century have had so far-reaching an influence on the sciences of physics, chemistry, and astronomy as those which have attended the perfection of the spectroscope, and no tale is so marvelous as The Story of the Spectrum.

VI

Pebbles

By PROFESSOR FRED L. CHARLES, M.A., Instructor in Biology, Lake View High School, Chicago

LITTLE pebble by the shore,
Tell me all thy journeys o'er;
Tell me of the storm and strife
Of a pebble's restless life.
Rudely cast upon the sand
By the billows, does the land
Offer thee a place of rest,
Or lovest thou the water best?
Do the wavelets in the night
Sing to thee of their delight
In the quiet of that hour
When the storm hath spent his power?
Do the breezes, blowing blue,
Whisper softly unto you
As they stoop to kiss the sand,
Happy to have reached the land?
Thou dost owe thy rounded form
To the beating of the storm.
In the oft-repeated shock
Of the wave against the rock
As the countless æons roll,
Thou hast gained thy perfect whole—
Buffeted 'twixt shore and sea
Till at last I set thee free.

PEBBLES

Full oft shall I, when by the sea
Of life's untamed activity
Myself like thee am tempest tossed,
Recall what thy perfecting cost;
And then, when on the sands of time
He walks who formed the plan sublime,
May I, though storms around me beat,
Be found by Him, like thee, complete.

In our rambles over hill and meadow or by the water side we may read in the pebbles that we find many a story of travel and adventure, and many a fascinating history may we learn of the times when the little rounded stone before us had not yet attained its beautiful form nor found its present resting place.

If our excursion lead us to the lake or ocean shore we may ask the pebbles whence and how they came, what agencies have worked them into this finished form, and what may be their destiny. On the banks of a laughing brook we find a pebbly host that can tell us of exciting journeys down the rapids above, of accidents on the way, and of less polished comrades left behind. Or it may be that we have found the pebble in the open field or in a gravel pit apart from any water. What a wonderful story this stone could tell us if we but knew its language! It might tell of snow and ice and glacier, of iceberg, torrent, and flood, of ages of grinding and crushing in icy darkness in its long, slow

journey southward. Perchance, during its struggle with the rocks beneath and the ice above, it has been worn flat upon one side or scratched and grooved with wounds not yet erased by the healing action of the water.

We may classify pebbles, then, according to their origin, into three groups:

1. Those formed by the agency of sea or lake.
2. Those formed by rivers.
3. Those formed by glaciers.

This division does not signify that in a group of miscellaneous specimens we can distinguish a river pebble from a lake pebble, etc., but simply indicates three different paths leading to the same result, the formation of a small rounded stone.

Let us first observe carefully the lake pebble; in the second study, the river pebble, we will investigate briefly certain geological forces now operating on the surface of the earth; while from the study of the glacial pebble we will learn something of that important geological period of which people in general are so ignorant.

Let us gather the pebbles ourselves which we are to study. This will add to our interest, and the search for suitable specimens cannot fail to develop our powers of observation and enlarge

our perceptive faculties. The pebbles we obtain we will sort with reference to the most prominent character which they present. For example, there should be a set of pebbles illustrating the effect of stratification; another set showing the wearing away of the softer material and the greater resistance of the harder portions, thus affecting the shape; a third set of specimens showing crystallization; a fourth set containing fossils, and so on. Let us place these on our study table, transforming it into a busy workbench, and we will find that a half hour with pebbles will arouse in us a desire to learn more about every lowly object in the weekday world around us. We will learn to know and love the near-at-hand and commonplace, to look for beauty everywhere, and to find

> "Tongues in trees, books in the running brooks,
> Sermons in stones, and good in everything;"

and henceforth a blade of grass, a snowflake, a waveworn stone, or an earthworm in its burrow will lead us into a more just appreciation of the Author of us all.

. . . . . .

Rocks are most naturally classified into two groups—sedimentary and igneous. Intermediate to these, however, are the metamorphic rocks, which, as the name implies, have been

altered or changed from their original condition, usually by heat, as, for example, limestone into marble.

Sedimentary or stratified rocks are formed in the water, usually at the bed of the ocean. Gravel, sand, and clay, when consolidated, form respectively, conglomerate, sandstone, and shale or slate. This consolidation of fragmental rocks is effected by three agencies—heat, pressure, and cement—working either separately or together. The conglomerate, arenaceous, and argillaceous groups are of mechanical origin, the material being derived by the erosion of the land, while limestone and coal are sedimentary rocks of organic origin.

Igneous rocks were at one time in a molten condition, and have generally become crystallized in cooling. Granite is of igneous origin. Gneiss, which from its appearance may be described as stratified granite, is a common example of the metamorphic rocks. The halftone at the head of this article is from a photograph of a gneiss pebble.

There are certain rocks commonly represented among pebbles which are easy to distinguish by even the simplest means of identification. As such we may mention limestone, quartz, granite, and diorite, though many more might be included.

Limestone pebbles are comparatively soft and yield to the constant wear upon them, becoming fairly regular and rounded in outline. The limestone common in pebbles and in building stone, however, is rarely pure, containing either magnesium or silica (quartz), associated with the lime in varying proportions. If magnesium predominates, the stone is called dolomite; if quartz is present in considerable quantity, the rock is known as siliceous limestone. These impurities increase the hardness and resisting power of the pebble and also darken the color. Often iron is present in small quantity, giving the stone a yellowish or rusty appearance. Limestone that has been crystallized through the agency of heat is called marble. With dilute hydrochloric acid (known also as muriatic acid) limestone effervesces, forming bubbles of carbonic acid gas (carbon dioxide), which is so well known as the froth in soda water. The effervescence may be very slight if the limestone is impure, but on the shell of a clam or an oyster a drop of the dilute acid will cause a marked action. Quartz is not affected by the acid; hence this serves as a characteristic test.

In the scale of hardness which follows it is seen that calcite (the mineralogical name for limestone, the latter being the petrological name), is number three, while quartz, the hard-

est common mineral, is number seven. A knife or nail will easily scratch limestone, but will have no effect on quartz; hence in the matter of hardness, also, we have a ready distinction between the two minerals. It must be remembered, however, that the magnesian and siliceous varieties which are so common are much harder than the pure limestone. One who is experienced can usually distinguish the limestone pebbles from the quartz simply by the sense of touch, the former presenting a gritty surface like the finest sandpaper, while a quartz pebble is more smooth and polished.

Limestone formations frequently contain small masses of quartz in the form of flint or chert. These are called nodules; and when a fragment of limestone containing a nodule of this kind is broken off from the rock and falls into the water, it develops into a pebble of very irregular form, the limestone part being worn and rounded, while the nodular portion stands out in bold and angular relief. Such pebbles are very common, for example, on the shore of Lake Michigan near Chicago.

There are three varieties of quartz, each of which is represented among lake pebbles. The vitreous, or glassy, variety is plainly crystalline and frequently forms little geodes, or nodules of stone containing a cavity lined with crystals.

A worn and tarnished exterior often conceals a beautiful mass of crystals, and it is then necessary to crack the stone in order to observe the crystalline structure. Rock crystal, amethyst, and smoky quartz belong to this variety. The chalcedonic variety of quartz is represented by the flint or chert pebbles. Because of their hardness they are usually irregular in outline; the color is generally brown, though sometimes grayish; the crystalline structure is not apparent, and the fracture is conchoidal, that is, they break with a curved surface. Chalcedony, carnelian, agate, and onyx are other examples of this variety. The third, or jaspery, variety is recognized in the jasper pebbles. In color they are bright red or dull yellow; the size is generally small, and the surface is smooth and polished.

Typical granite is composed of three minerals, quartz, feldspar, and mica, in varying proportions, but the term is loosely and popularly applied to cover many kinds of rock. Small crystals are the result of rapid cooling, while large crystals indicate that the molten rock was not exposed to the surface, and therefore cooled slowly. The quartz is recognized by its hardness and by its glassy appearance; the feldspar by its hardness (less than that of quartz), its color (usually red or gray), and by the fact that it splits in an even surface; while the mica is identified by

means of its softness, elasticity, and laminated structure, that is, its occurrence in thin plates or layers. When the granite cooled from its original molten state, the quartz was the last to solidify, and hence is irregularly distributed throughout the rock, filling spaces between the earlier formed crystals of mica and feldspar. There are many varieties of granite—often hornblende is substituted for mica, etc.—but it is not within the scope of this article to enter into a detailed discussion of these variations.

Diorite is the rock of which many of the black pebbles are composed. It consists of two minerals, feldspar and hornblende. Sometimes the pebbles are composed almost entirely of hornblende. The hardness of these black pebbles is about six, and their outline is generally rounded.

The hardness of a mineral is easily determined, and affords a valuable aid in its identification. The following ten minerals, numbered in the order of increasing hardness, constitute what is known as the scale of hardness. Any mineral is scratched by one above it in the scale, and in turn will scratch those below it. Those above seven are precious gems.

The scale, with the appended suggestions, will be found helpful in determining the mineral composition of pebbles.

SCALE OF HARDNESS.

1. *Talc.*—Easily scratched by thumb nail.

2. *Gypsum.*—Not easily scratched by thumb nail; does not scratch copper.

3. *Calcite.*—Scratches, and is scratched by, copper.

4. *Fluorite.*—Not scratched by copper; does not scratch glass.

5. *Apatite.*—Scratches glass with difficulty; easily scratched by knife.

6. *Feldspar.*—Scratches glass easily; not easily scratched by knife.

7. *Quartz.*—The hardest common mineral; not scratched by knife.

8. *Topaz* or *Emerald.*

9. *Sapphire* (or *Emery*).

10. *Diamond.*

. . . . .

Armed with this knowledge let us make three little excursions into the realm of pebbles, choosing as the scene of the first a pebbly cove, confident that here we shall find much to repay us for a glance at the pebbles which lie glistening in the sun or sparkling in a bath of spray.

A PEBBLY COVE.

Every pebbly cove along the shores of our lakes is but a nook in a vast library where every stone is a book of fairy lore. Many persons

roam among these beautiful volumes and read not a word, yet here are stories, if they but knew it, that could not fail to charm.

Let us linger here and read what most attracts us. We find a great variety in form, size, and color, and in mineral composition, among the beach pebbles, thrown up as they are by waves which may have gathered them from a thousand different fields.

Soft pebbles are more likely to be regular in outline and smooth in surface than those of hard material. If the stone is composed of more than one kind of mineral the softer mineral often yields to the destructive agencies, as erosion, or chemical decomposition, producing small indentations in the surface, while the harder and better preserved portions stand out in relief. If a nodule of some harder kind of rock is present, the pebble may in consequence assume a very peculiar, irregular form.

The color of the worn or exposed surface may be quite different from that of a fresh surface. The exposed part may have faded; or it may have become stained, or "tarnished," by some substance (for example, iron) contained in the water; or the crystalline surfaces may have been so obliterated by the wear upon them that the reflection of light from the exposed portions is different from what we see in the fresh surface.

Crystalline structure presents an interesting field for study, but we cannot enter into a discussion of it here. Crystallization is accomplished in three ways: (1) by fusion (melting) and subsequent cooling, as in granite; (2) by solution and subsequent evaporation, as in quartz geodes; and (3) less frequently by sublimation, that is, by vaporization and subsequent condensation, for example, sulphur in the craters of volcanoes.

Stratified rock tends to form flat pebbles, such as the boys call "sailors," the strata or layers, with rare exceptions, running lengthwise. As the stone wears away, especially if it is composed of soft material, layer after layer breaks off, always leaving the stone flat, so that it is almost impossible to form a spherical pebble out of clay, shale, or slate. If the longer axis were at right angles to the planes of cleavage, the pebble would soon break in two, continuing to do so until the normal flat condition was reached. The pebble pictured above, though composed of very hard rock, owes its partial flatness to its stratification.

We occasionally find a well-worn pebble from which a fragment has been violently broken at some recent time, as is shown by the greater angularity of the broken edge. Fragments of bricks, which are often found along the shore,

where man has been, serve as excellent illustrations of the effect of water erosion. I have known quite young children to readily trace the following history in a brick: A perfect brick had been thrown into the water, where, as shown by its rounded edges, it had remained for a considerable length of time; it had then been cast upon the shore, where it was violently broken. The waves had again claimed it, and after partially smoothing the freshly broken surface, had once more tossed it upon the shore, where it was found by our party, who, encouraged by this find, renewed the search with augmented zeal.

The pebbles suffer the greatest erosion, not from the force of the water against them, but from the grinding of stone upon stone, and from the scratching they receive from the sand which lodges between them. In the manufacture of marbles we imitate the making of pebbles on the beach. A large number of cubical fragments of hard stone are put into a mill, and by the grinding process to which they are subjected they are worn into spherical form. The cheaper marbles, however, are molded and baked.

Where a crescent-shaped beach terminates at both ends in rocky cliffs we find the pebbles graded both as to angularity and size. Broken from the cliffs by the action of the frost or by

the waves, a fragment of rock is gradually carried toward the center of the hollow, breaking and being smoothed and rounded as it goes. Hence we find the smallest and smoothest pebbles near the center, and the largest and most angular near the ends of the crescent. Such beaches are very common on rocky shores.

On the shores of our lakes we may find many pebbles containing fossils, such as different forms of coral, crinoids (popularly known as "stone lilies"), and often brachiopods and mollusk shells. Plant fossils are also found, but they are not so common. Most of us are familiar with coral skeletons. It is an interesting fact that most of the coral pebbles are silicified, that is, though originally composed of limestone, quartz has taken its place. The stone lily stems are very common in pebbles, but the body or head is rarely found. The fragments of the stem are usually buried in the body of the pebble, where they are seen either in transverse or longitudinal section, but they sometimes occur loose, and are then known by many as "Indian beads." Like the coral skeleton, the crinoid fossils, though originally of limestone, are often silicified. Another rock-building animal, much smaller and simpler, but none the less important, is the Foraminifer, a microscopic form which secretes a calcareous (lime-

stone) shell. Though not recognized in the pebble, the minute and beautiful perforated shells of these wonderful little denizens of the sea, constantly raining upon the ocean floor as the animals die, constitute a very important factor in the formation of limestone.

By the separate or combined agency of heat, pressure, and cement, the hard, stony coverings or skeletons of these different animals are finally consolidated into limestone rock. When the cementing material does not fill all the interstices, the rock is loose and porous. The rock underlying Florida is built largely in this way from the skeletons of corals and mollusks.

It is interesting to inquire as to what is the final fate of pebbles. If the wear is long continued the pebbles are converted first into gravel, then into sand, and finally into clay or mud. Quartz rock is so hard that it rarely becomes mud, being reduced into nothing finer than the angular grains of sand. Most minerals finally yield to the friction upon them, and form mud; and hence most sand is composed of quartz.

"Conglomerate" is a form of rock composed of pebbles in a cementing mass of some finer material, for example, sand. If the pebbles are angular in form the stone is called "breccia" (pronounced *brĕt'-cha*); if they are rounded it is known as "pudding stone," from the resem-

blance of the pebbles to the plums in a pudding. Artificial stone sidewalks and the bottom layers of cement floors in basements closely resemble pudding stone.

The conglomerate rock may be metamorphosed so as to lose its original character, and the entire shore line may be elevated, as is now taking place in the Scandinavian peninsula, so that the consolidated sediment becomes once more a part of the surface of the earth, and a new cycle is begun.

Down Stream with a Pebble.

As we go from the source of the river toward its mouth, we find the pebbles constantly decreasing in size and losing their angularity. This is due, of course, to their having been subjected to more wear, and this gradation in size and form applies as well to the successive stages in the history of any one pebble as it is carried down the stream by the current.

What an object lesson in the development of character! Starting as it does upon its life journey at the head of the stream, with many angularities that mark its immaturity, we may follow the pebble down stream, see it knocking about in the world, until all its rough edges are rubbed off by contact with its fellows and its development is complete, and finally following the

course of all created things, it returns to dust again,

"To mix forever with the elements."

Thus may we profit much from the contemplation of these common objects and of the forces which have taken part in their formation.

Ready, then, for our river trip. We are to observe where the current is swiftest; where deposition has taken place; follow the hurrying stream in its busy task of tearing down material here, transplanting it down stream, and building up the bank or bed beyond. There is much to be done. Our river obtains the material out of which it is to form the pebbles either from its bed or from the banks, or from the stones and bowlders which are washed into it by freshets or drop into it from the rocks above. If not loosened by the erosion of the stream they may be detached by the agents of weathering. Of these agents, frost is perhaps the most important. Water, contrary to the general law, expands in freezing, and the expansive force of the ice in the crevices of rocks is a large factor in the formation of soil. Chemical decomposition aids materially in breaking up the rock. The alternate expansion and contraction of the rock itself during the change of day and night, or of summer and winter, is a severe strain upon it, especially if it is composed of different min-

erals which expand unequally. Lastly, organic agencies, for example, the burrowing of earthworms and the penetration of the rocks by the roots of plants, aid in breaking up rock and forming soil.

During the winter the action of the frost furnishes the river with a large amount of material, to which is added what is washed into the stream by the spring freshets; but these same freshets with their powerful currents enable the river to dispose of the accumulation. If a rock is so large as to successfully resist the current, the constant chipping away of fragments by the expansive force of the ice in the crevices in winter may finally reduce it to a size which the current can handle. It must be remembered that a substance does not weigh as much in water as in air, since the buoyancy of the liquid tends to lighten it. The principle may be illustrated by means of a pair of scales with a stone hanging by a string beneath one scale pan and balanced by weights on the other. If a pail of water is brought up so as to submerge the stone, the opposite side of the scales will fall, showing that the weight of the stone is diminished, the amount of weight lost by the stone being equivalent to that of an equal volume of water.

A river pebble may owe its flatness to stratification, or to its having been formed from a

flat ledge of rock, or to having been pushed along on the bed of the river without rolling, thus being worn on one side only. If the stone is originally flat, the stream finds it easier to slide it along than to roll it. A large stone projecting above the bed of the river is slowly worn away on the top by the stones and sand which pass over it. When the water is low these flat rocks rise as "stepping-stones" above the surface.

To be well adapted for the formation of pebbles the stream must have a rapid slope and a rocky or stony bed. Rounded pebbles are best formed in a pothole, where the water circles in an eddy. If the bed of the stream is muddy, the pebbles will sink into the sediment and escape erosion. The transporting power depends mainly on the velocity of the current. An exceedingly slow current will carry fine mud or sand, while a velocity of three miles an hour (about three feet a second) will move a stone the size of a hen's egg. By observing floating objects we can easily see that the current is most rapid near the middle of the river and slowest next the banks, where it is retarded by friction. The bed of the river also serves to check the current, so that the surface water moves faster than that at the bottom. A wise fish would go down stream near the middle at the surface,

and, returning, would go up stream at the bottom and along the sides.

If the river is charged with sediment, any lessening of the velocity results in deposition. In the case of a river which is subject to overflow, the bed and the banks may be buried beneath a layer of sediment. The Mississippi has built itself up in this way, by successive deposits, until in some places it is above the surrounding country.

Where the course is winding, causing the sinuous current to strike first one side and then the other, the river shifts its position as a result of erosion and deposition. The "oxbows" are formed in this way, and the course sometimes becomes so winding that the river cuts across and forms an island, the deserted portion often becoming a lagoon or bayou.

When the rock material, in the form of gravel, sand, or clay, finally reaches the sea, the large body of water checks the current of the river, causing it to deposit its burden. The coarsest material is laid down first; farther from the shore the sand is dropped; while the fine clay is often carried far out into the ocean. In ages to come this sediment on the ocean bottom may be consolidated and elevated above the water in the form of stratified rock, again to be attacked by the agents of erosion, as we learned

in our former excursion. Thus we find creation ever continuing; "through the ages one increasing purpose runs;" the processes of nature are God's ways, and when we study them we are learning of him: *"Per naturam ad naturæ Deum."*

HISTORIAN OF AN ICY AGE.

We have now to make the acquaintance of a third kind of pebble, one that can tell us of the time when the snow king held unlimited sway, and sent his forces of snow and ice to invade our land.

In the Northern States the glacial pebbles predominate, the rivers and lakes serving largely to sort and finish what might be called the raw product brought to them by the great sheet of ice which covered these States in recent geological times.

This great continental glacier gathered all loose or available material as it came, grinding it into soil, or transporting it, in more or less modified form, to a more southerly locality, where it was dropped as the ice melted. Lakes and rivers are now operating, in part, upon much of this material, elaborating it into what we recognize as the lake or river pebble. On the prairies and in the fields, likewise, we may find scratched glacial pebbles, or even bowlders, that

have been flattened on one side. Why the ice invaded our country and why it retreated are unsolved problems, though various theories are presented.

The most interesting glacial pebble is one that is worn flat on one side, the great pressure to which it has been subjected serving to polish the worn surface. This surface is usually found to have been scratched or grooved by portions of harder rock which rubbed against it. Sometimes a stone has two flat surfaces, showing that it has been overturned in the ice; but unless subsequently acted upon by water, it is likely to be of an irregular, angular form except for one "glaciated" surface.

The selective wearing which is characteristic in the lake pebble, causing the harder portions to stand out from the general contour, is not present in the action of the glacier, which scours off even the hardest rock.

If the stone has not been recently broken, the scratches, or striæ, will, in general, run lengthwise on the stone. If the longer axis lay in the ice at right angles to the direction in which the glacier was moving, the stone would meet many obstacles, and hence be either broken or turned a quarter way round, so as to encounter less resisting surface.

The scratches, of course, show the direction in

which the ice traveled; often they cross one another, indicating that the stone changed its position in the ice, or that the glacier changed its course.

The pebble may have been imprisoned in the ice at the bottom of the glacier, or it may be a fragment of the polished rock over which the glacier moved like an immense sheet of sandpaper.

Gravel, sand, and clay are formed beneath glaciers, the soft or crumbling rock being the first to yield.

A powerful pressure is exerted by the great weight of perpetual snow at the head of the glacier, causing it to move down the mountain side like a river of ice. Ordinarily the movement is but a few inches a day, though in some instances it approaches one hundred feet. Though the motion may be so slow as to be unnoticed except by a careful observer, yet the resultant erosion of the underlying rock is none the less severe.

At the foot of many glaciers is an ice cave, from which flows the water which has found its way down from the surface. Many rivers, for instance the Rhone, originate in this way, their waters being laden with pulverized rock from beneath the glacier.

The pebbles and bowlders dropped by the

glacier are often so different in composition from the native rock of the country as to attract immediate attention. Fragments of copper ore, peculiar to the Lake Superior region, or of coral from northern Michigan, worn smooth and round, may be found throughout northeastern Illinois, where the ice left them in its slow retreat. If we explore the country to the north we may discover perhaps the very locality from which these specimens came. The great ice sheet brought with it not only what was found loose upon the surface, but also all that it could obtain by its own erosive power. Hence in the glacial "drift" we find bowlders, stones, pebbles, gravel, sand, and clay.

The surface of a valley glacier near the margins is strewn with rocks of varying size which have been torn from the sides of the valley or which have fallen down from above. These marginal accumulations are known as *lateral moraines*. A mass of rock which falls thus upon the ice is carried as a floating body as easily as a small stone. When two glaciers unite two lateral moraines are brought together, forming a long line of rock and soil near the middle of the glacier, called a *medial moraine*.

If a stone remains on the surface it will not receive the peculiar markings which have been described. However, there are usually many

crevices in the ice, and if a stone drops into one of these it may work its way down to the bottom of the glacier to join the material torn from the bed rock. This accumulation is known as the *ground moraine;* it is here that gravel, sand, and mud are formed, and that the glacial markings are made by the friction of rock against rock.

When the ice melts, the material composing the lateral, medial, and ground moraines is deposited in a common heap at the foot of the glacier, constituting the *terminal moraine.* If, as is frequently the case, a large bowlder be deposited on the summit of a hill which was covered by the ice, it is known as an "erratic." No force of water could have elevated the bowlders to such a height, and water would not have left them in so insecure a position.

By driving a row of stakes across a glacier in the Alps, and observing their change in position, it was proved that the middle moved faster than the sides. Later, a place was found where a vertical row of stakes could be driven into the side of the glacier, and by this means it was proved that the surface moved faster than the bottom. This differential motion is the result of friction on the sides and bottom, and thus the movement of a glacier is comparable to that of a river.

The glacial sheet which existed here at one time has left many evidences of its presence. The vast amount of transported material, much of which we can trace back to its source; the peculiar markings on the pebbles and on the rock over which they passed; the position of the "erratic" bowlders; the modified course of rivers, etc., etc., all point to the action of ice. From Long Island to central Illinois, and then to the State of Washington, runs a line which marks, in general, the southern limit of glacial invasion. Much of our land owes its fertility to the nature, depth, and extent of the glacial drift.

Valley glaciers are now most numerous in Alaska, though they are best known in the Alps and hence are sometimes known as Alpine glaciers. Greenland is almost entirely covered by an immense continental glacier, a sheet of ice like that which covered our own country.

It is many thousand feet in depth, so that the peaks of high mountains may barely rise above the ice. It is thickest in the interior, and moves slowly to the sea. When a glacier extends into the ocean, the buoyant force of the water, aided by the beating of the waves, sooner or later breaks off the submerged portion, and forms an iceberg.

During the glacial period, however, the onward career of the ice sheet was checked by the sun before the sea was reached where icebergs could be formed; and to-day, spread broadcast over our Northern States, we find the glacial pebbles, eloquent historians of an icy age.

VII

Chemical Recreations

By ARTHUR E. CHAPMAN

To the beginner in scientific study no subject seems to border so closely on the magical as chemistry, and many a boy or girl after a year's work in the high school laboratory has discovered that the most beautiful experiments and the most bewildering results are comparatively simple of performance and are easily explained. No science is as mathematically exact or as free from the fanciful and the mysterious as chemistry, and few, if any, possess a greater educational value in the development of true brain power rather than of brain storage capacity.

The following experiments may be easily performed in an hour, and can be readily explained by most high school graduates. The materials, with few exceptions, can be procured at most drug stores, and the apparatus is found in most well-equipped households. The explanatory remarks, if given after each experiment by a person interested in such things, will make an evening's entertainment of great interest and value. If such a plan is followed the work

should all be done in advance of the entertainment planned. Facility in handling will thus be acquired, and failure from lack of attention to detail will be avoided. Nothing is more annoying than to find oneself a false prophet even in a small matter.

1. PHARAOH'S SERPENTS.—A half teaspoonful of sulpho-cyanate of mercury placed in the middle of a large plate is lighted, and burns slowly, swelling up to many times its original size. If scales are at hand it can be shown that the large mass produced weighs less than the original quantity. If the cyanate is made up into pellets before lighting they will spin out into long serpentlike masses which give the experiment its name. If now we ask what has become of the material which the scales show has gone from the plate? the good observers will say, "It went up in smoke." It was not, then, destroyed, but is floating in the room. Well, where did the great increase in size come from? The material just swelled up and the particles separated a little farther than before. This change in size without change in mass or amount of matter is a common occurrence in nature, and in every case careful observation will show that matter is not destroyed, but is only changed in form, size, or color. This fact is embodied in a law known as "The Law of Conservation of Mass."

Stated briefly, it is, "No particle of matter can be destroyed."

2. SPONTANEOUS COMBUSTION.—Dissolve a piece of phosphorus the size of a pea in a teaspoonful of carbon bisulphide. Pour the solution over some pieces of soft paper about six inches square. Hang these papers on a wire some distance from each other. In a few minutes, as soon as they are dry, the papers take fire and burn. (Handle these substances carefully, as both are very poisonous. Cut phosphorus under water.)

Why did the papers burn? What set them on fire? What is fire, anyway? All these questions suggest themselves in this experiment. Any boy in a chemistry class would say, "Fire is the union of some substance with oxygen, producing heat and flame." And he might add that "the oxygen ignited with the phosphorus." That is true. Another important fact is that phosphorus burns (unites with oxygen) at a very low temperature, even lower than that at which water boils. But here another question presents itself. Why did not the oxygen burn the phosphorus in the lump on the table? Why does it not burn that which we know is on the head of every match? Let us answer that by asking another. Why do we kindle a fire with shavings, then small splinters, sticks of wood, and,

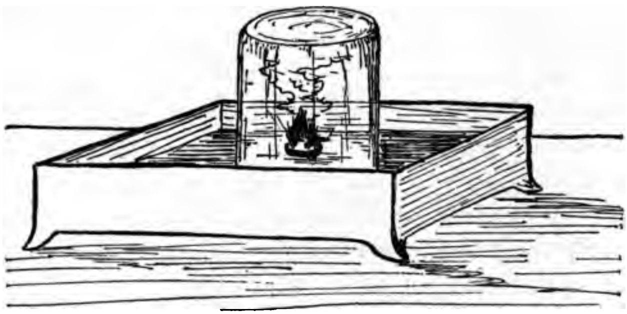
lastly, put on the coal? You would say at once that the fire has a better chance at the small pieces. And just so with the phosphorus; the oxygen gets at the minute little particles of phosphorus which the carbon bisulphide left scattered over the paper when it evaporated. Like the shavings, the finer particles burn at a lower temperature than the large ones. Well, here is another question. This experiment is just full of interrogation points. Where did the oxygen come from? "O, it's in the air," the smart boy immediately answers. Well, is the air all oxygen? The smart boy may not be able to answer that one. Let us see how the man of science goes at it to find out. If we recall our first experiment we know that when the oxygen unites with the phosphorus it must form something else; for nothing can be destroyed, it can only change. What did they form? Why, that white smoke which we saw passing off from the paper—and that smoke was a solid which dissolves readily in water. From these facts some ingenious man has devised this experiment:

3. THE AMOUNT OF OXYGEN IN THE AIR.—On a basin of water float a flat cork about two inches in diameter—or, better, a small pepper-box cover. In it place a piece of phosphorus the size of a pea. Light the phosphorus and cover quickly with a large glass jar—a two quart

fruit jar will do. Allow it to stand until the white smoke falls and dissolves in the water, then measure the height of the water inside the jar, and also the height of the jar (Fig. 1).

Some one has said that "an experiment is a question intelligently put to nature." Here, then, is nature's answer, we must put it into words for ourselves. The oxygen united with the

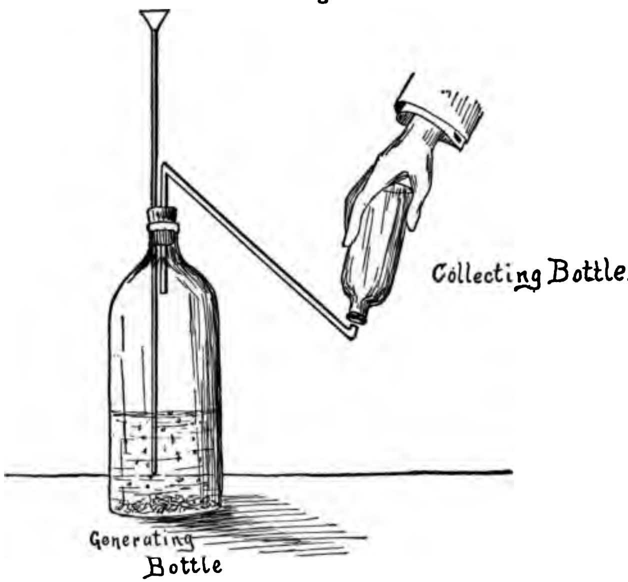
Fig. 1.



phosphorus to form the white smoke; the smoke dissolved in the water. Then the water now fills the place before held by the oxygen. It is only a question, How much water have we? Water is easily measured; we can see it, and we could not see oxygen. Suppose the water has risen two inches in the jar, and the jar is ten inches high. The oxygen, then, must be about two tenths, or one fifth, of the air. If a mouse were placed in the jar the water would rise the

same distance. For he consumes oxygen. We can now show that there is no oxygen in the jar by putting in it a lighted taper. It is immediately extinguished. Numerous similar experiments, carefully and accurately performed,

Fig. 2.



prove that our answer is about right. Oxygen is about one fifth of the volume of the air.

4. EXPLOSION OF HYDROGEN AND OXYGEN.—In a pint bottle place two ounces of granulated zinc and pour on it a solution of one ounce of hydrochloric acid in four ounces of water. Fit

the cork with a delivery tube. This is called a generating flask (Fig. 2). When it has been running for five minutes partly fill a glass bottle with hydrogen, as shown in the cut. Hydrogen is so light that it flows up. Remove it from the supply pipe and apply a lighted match to the mouth of the bottle. A sharp report follows. Here we have a combustion so rapid that we call it an explosion. The oxygen of the air united with the hydrogen to produce a new substance. The fog on the inside of the bottle shows us that this new substance is water, formed by the union of two gases, both of them invisible, tasteless, colorless, and odorless. In fact they can hardly be detected except for their behavior with the flame. Now light the jet of hydrogen which is issuing from the generating bottle. If this manufactory of hydrogen has been in operation long enough to drive all the air out of the flask there will be no explosion as in the first place. The hydrogen burns quietly with a pale blue flame, hardly visible, yet very hot. Holding a cool glass plate over the flame for an instant small drops of water will gather on it, as dew. Here is an interesting series of facts. Two elements by their union make the hottest flame known; and form, as a product, water, the enemy and extinguisher of fire.

Let us see a few further illustrations of the

union of oxygen with other elements. Phosphorus united with the oxygen of the air, burning readily, and hydrogen united still more rapidly in the explosion just witnessed. Now try two substances which have such an attraction

Fig. 3.

for oxygen that they will take it out of the water, which, as we just now saw, is made from oxygen and hydrogen.

5. BURNING OF SODIUM ON WATER.—Fill a glass candy jar two thirds full of lukewarm

water. Drop on the water a piece of sodium the size of a small hazel nut, and apply a match to it. It spins rapidly about and appears to burn with a pale blue flame. (Caution: Do not touch the sodium or potassium with the fingers. Stand so far away from the jar that any slight explosion at the end will not throw the sodium in the face. Fig. 3.)

6. Drop a small piece of potassium on the water. It takes fire immediately and goes up at last with a sharp pop. (Caution above.)

How can this apparent burning be explained? These two substances, sodium and potassium, have such an attraction for oxygen that they take it from the hydrogen, they burn it out of the water. But this union of these metals with the oxygen is not what causes the flame. The hydrogen which is set free unites with the oxygen of the air, burning with the pale blue flame which was noticed at the mouth of the generating flask.

Having experimented with the two elements which unite to form water, let us now try a few of the commonest of the chemist's experiments with water itself. The greatest value which water has for us is in its use as food, and in consequence its purity vitally concerns us. In the chapter on Useful Bacteria it is shown that these little plantlike animalcules are a source of dan-

ger to health, and that their presence in water is due to the existence in the water of organic matter. Our first test, then, will be a question asking various samples of water to tell us whether or no they contain injurious quantities of organic matter.

7. WATER TEST FOR ORGANIC MATTER.—Fill three tall glass jars with equal quantities of water procured as follows: The first with water from a well, the second with distilled water, and the third with water from a ditch near a barnyard. See that all look clean and clear. To each add from ten to twenty drops of a solution of potassium permanganate. Add the same quantity to each, making as nearly as possible the same color —a bright, clear purple. Allow them to stand for half an hour in a warm place. The ditch water will have lost color, becoming possibly a dirty brown; the well water will have bleached slightly, or none at all; the distilled water will not have changed. If distilled water is not obtainable carefully boiled well water will do for this experiment.

What has caused the change? The ever-active oxygen is again partly responsible. The minute quantities of oxygen and of carbon dioxide set free by the ever-present bacteria have united with the coloring matter to form other and colorless substances. Any water which in several

hours will bleach in this manner is not fit to drink.

Another test which has a distinct bearing on the purity of water for drinking purposes is that by means of which chlorides are identified in water. The waste matter thrown off from animal bodies always contains compounds of chlorine, known as chlorides. Excess of organic matter is nearly always accompanied by chlorides. As these salts are very soluble in water we may also find them in well water as mineral chlorides, commonly of lime and magnesium. These are not particularly injurious.

8. WATER TEST FOR CHLORIDES.—To the three samples of water mentioned before add small quantities of a solution of silver nitrate, dissolved in distilled water. Those containing chlorides will become milky in appearance. Here is an example of a process which is of inestimable value to the chemist. It is called precipitation. It means the formation of particles of a solid in a liquid by the union of two or more substances dissolved in the liquid. This new solid is not soluble in this liquid, and so of course if given time enough falls to the bottom, or is "precipitated." The substance which is formed in our experiment is silver chloride, one of the few chlorides which does not dissolve readily in water. It does, however, readily dis-

solve in ammonia water. This can be easily shown by pouring an equal quantity of the ammonia into a tube partly filled with the water most clouded, when the solution is again as clear as at first.

The chief value of these two processes just witnessed, called respectively "precipitation" and "solution," lies in the fact that they furnish a means for the identification of nearly all the elements and many of the compounds known to scientific chemists. No two substances behave exactly alike under many similar circumstances. In this respect they are like people; they have their individual peculiarities. Now, we all know that nearly all metals unite with other substances to form compounds that do not appear at all like the elements from which they were formed. If iron, copper, lead, or arsenic never existed in any other form than that of absolute and elementary purity it would be an easy matter to always recognize them. And yet, such a condition of affairs would have its drawbacks, particularly to the physcians. It would be rather hard for them to convince people who need toning up that a dose of carpet tacks was the right thing, or to induce a crying baby to take a few bullets. And yet iron is the thing needed by many rundown people, and lead in small quantities is soothing in its effects.

The recognition of a few of our common metals may be hinted at in a few tests which show characteristic precipitates or solutions for iron, silver, copper, antimony, lead, and mercury.

9. COLORED PRECIPITATES.—Prepare twelve test tubes as follows:

No. 1 Five grains of potassium sulphocyanide in one half ounce of water.

No. 2. Ten grains of ferric chloride in one ounce of water.

No. 3. Ten grains of common salt in one half ounce of water.

No. 4. Ten grains of silver nitrate in one ounce of distilled water.

No. 5. Ten drops of ammonium hydroxide in one half ounce of water.

No. 6. Ten grains of copper sulphate in one ounce of water.

No. 7. Ten drops of ammonium sulphide in one half ounce of water.

No. 8. Ten grains of antimony chloride in dilute hydrochloric acid.

No. 9. Ten grains of lead nitrate in one ounce of distilled water.

No. 10. Ten grains of potassium chromate in one half ounce of water.

No. 11. Ten drops of ammonium sulphide in one half ounce of water.

No. 12. Five grains of mercuric chloride in one ounce of water.

(A few drops of hydrochloric acid in the second and sixth will help to keep them clear.)

These solutions are all perfectly clear, though shades of color may be detected in some of them.

Now pour some of the second into the first,

and shake it up. The ruby red color resulting is a test showing the presence of iron. Pour the fourth into the third, the sixth into the fifth, and so on, putting the even numbers into the odd just preceding. No. 3 will be white, a salt of silver; No. 5, blue, indicating copper; No. 7, orange, produced by the antimony; No. 9, yellow, lead; and No. 11, black, colored by the mercury.

These colored precipitates are but the beginnings of a series of tests by which we can absolutely identify most metals, even though they are present in very small quantities. It is also evident that these colors lend themselves to the formation of dyes and paints. This yellow, for instance, is the substance used in paints of this color, being known as "chrome yellow."

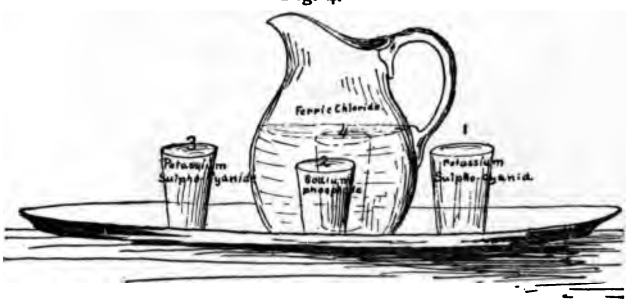
Our last experiment, known to magicians as "The water and wine miracle," is but an adaptation of the first test for iron just shown.

10. WATER AND WINE.—Prepare a small tray bearing a glass pitcher and four tumblers. In the pitcher place eight grains of ferric chloride dissolved in three pints of water. The addition of a little hydrochloric acid will keep it perfectly clear. In glass No. 1 put four grains of potassium sulphocyanide dissolved in a little water. In No. 2 place one hundred and sixty grains of sodium phosphate dissolved in a little water. In No. 3 the same as No. 1, and in No. 4 nothing.

These glasses, partly covered by the edge of the tray, will appear empty. You might invert No. 4 to show that they are empty (Fig. 4).

By all good magicians these would be carefully prepared and tested before facing the audience. Then pour from the pitcher of clear water into the first tumbler a glass of wine. It will turn ruby red the instant it touches the glass. Into the second pour a glass of water;

Fig. 4.



into the third, a glass of wine; and into the fourth, another glass of water. Now pour Nos. 1 and 2 together, then pour back into the pitcher. Lo, there are two glasses of water. Pour 3 and 4 back and forth and there are two glasses of wine. Return them to the pitcher, and there is, as at first, a pitcher of clear water.

This experiment makes no pretense to educational value, though it points a moral at a less distance than many another tale. The sulpho-

cyanide of potassium, which produces the red color with the iron, is a deadly poison, producing almost instant death. In this respect it is much kinder than the wine it represents.

The explanation is easy. As you saw in the first test, in the ninth experiment, a solution of ferric chloride turns ruby red when mixed with sulphocyanide of potassium. This red solution is bleached out by any phosphate. So, fill the pitcher with the solution of iron salt, and the two glasses which are to receive the wine should contain a little of the cyanide, and the one which is to bleach the others should contain a saturated solution of phosphate. The effect is quite startling but easily understood.

These experiments, four with the air, four with water, and two on the behavior of metallic salts, have been selected with a view to stimulating an interest in the common things about us, and disclose the possibilities which they afford for entertainment and instruction.

CAUTIONS.

Care should be taken that all apparatus is clean.

Some of the substances must not be touched with the fingers, as severe burns might result; these are potassium, sodium, phosphorus, and silver nitrate. Others are quite poisonous, and all should be handled with care.

MATERIALS AND APPARATUS NEEDED.

One dozen six-inch test tubes.
Two feet of one quarter inch glass tubing.
Four ounces granulated zinc.
Two quarts distilled water.
One tenth ounce phosphorus.
One tenth ounce metallic sodium.
One tenth ounce potassium permanganate.
One quarter ounce sulphocyanide potassium.
One quarter ounce ammonia sulphide.
One tenth ounce lead nitrate.
One quarter ounce sodium phosphate.
One half pound hydrochloric acid, commercial.
One ounce ammonium hydroxide.
One quarter ounce copper sulphate.
One half ounce sulphocyanate of mercury.
One quarter ounce carbon bisulphide.
One tenth ounce metallic potassium.
One tenth ounce silver nitrate.
One quarter ounce ferric chloride.
One tenth ounce potassium chromate.
One tenth ounce mercuric chloride.

Richards & Co., Limited, Chicago, Ill., have offered to furnish the above list of materials, carefully packed and labeled, for three dollars.

VIII

Corals and Coral Formations

Adapted from LE CONTE'S *Outline of Darwin's Subsidence Theory*

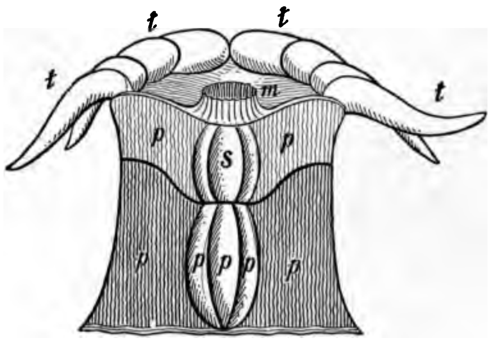
THE prominence of the various Florida "keys" in recent Cuban affairs has, doubtless, led many young persons to ask what is the nature of these keys and how they are formed. An adequate answer will require a description of corals and coral formation.

What is popularly referred to as a "coral insect" is scientifically known as a polyp. A simple polyp, such as may be seen clinging to rocks or piers on our seashores, may be compared to a hollow, fleshy cylinder, closed at both ends like a yeast-powder can. The lower may be called the foot disk, the upper the mouth disk. The edge of the mouth disk is surrounded by hollow tentacles which open into the hollow cylinder. In the center of the mouth disk is the mouth, and below it hangs the stomach, reaching about half way down. At the lower end of the stomach is the pylorus, which may be opened and shut like a second mouth. Running from the outer wall, and converging toward the axis, are many partitions, some of which

reach the stomach and hold it steadily in the axis, but below the stomach terminate in free scythe-like edges. These converging partitions divide the body cavity into a number of triangular apartments which, however, are in free communication with each other below the stomach.

Now, a simple coral has a similar structure,

Fig. 1.



Ideal Section of Single Living Coral.

t, tentacles; *s*, stomach; *p p*, partitions. The shaded portion contains carbonate of lime.

except that stony matter (lime carbonate) is deposited in the lower part as high as about the region of the stomach. When the animal seems to disappear, it only withdraws the soft upper parts within the stony lower part. But the stony material is everywhere within the living organic matter, and covered. When the living organic matter is taken away, as in *dead* corals,

then we have only the radiated structure of the lower part in stone (Fig. 1).

Many lower animals, like plants, have the power of reproducing by buds. If the buds separate they form distinct individuals, but if they remain attached then a compound animal is formed, composed of many individuals united together—precisely as a tree is formed of many buds, each of which is in some sense an individual and capable of independent life. In the compound coral each bud has its own tentacles, mouth, stomach, partitions, and other organs necessary for life, and yet all are organically connected and each feeds for all. There is, therefore, a sort of individuality in the aggregate, but a more decided individuality in each bud. The form of the aggregate depends on the mode of budding. If the buds grow into branches then there is formed a tree coral; but if the buds do not separate, but remain connected to their ends, and form new buds in the intervening spaces, then they form a head coral. There are all gradations between these extremes. Coral trees are often from six to eight feet high, so that one may literally climb among the branches. Coral heads form hemispherical masses fifteen to twenty feet in diameter. In either case the aggregate consists of hundreds of thousands of individuals; in either case, also,

the living organic matter is confined to the superficial portion, one quarter to one half an inch thick. As in case of a tree so in corals, life passes continually outward and upward, leaving the middle parts dead, and, in fact, wholly composed of mineral matter (lime carbonate), retaining, however, the peculiar structure given it while permeated with living matter.

Corals, however, reproduce also by eggs. These are formed within, below the stomach, extruded through the mouth, and having, like the eggs of many lower animals, power of locomotion, swim away and settle to the bottom where, if conditions are favorable, they form single corals, which, by budding, soon form coral trees or coral heads. In this way a coral forest or grove is formed, and spreads in all directions as far as favoring conditions allow.

Coral reefs are formed by the growth and decay on the same spot of countless generations of coral forests. Each generation in its death leaves its limestone behind; and thus the coral ground rises or is built up without limit except by reaching the sea level.

Coral islands are made by the action of the waves. Waves will form islands on any kind of submarine bank when the water is shallow enough for the waves to touch and chafe the bottom. When, therefore, the reef rises near

the surface the beating waves will break off coral trees, coral heads, and even masses of the reef rock. Great masses are thus rolled up on the inner side of the reef and form a nucleus about which other masses gather. Among these larger masses smaller masses are thrown. Then coral sand is sifted among these and the whole is cemented into a solid rock by carbonate of lime in the sea water. The island rock, therefore, is a breccia of coral limestone. The island thus formed is at first barren rock; but, slowly, seeds are brought by waves and wind; it becomes covered with vegetation, and inhabited by animals and by man.

There are three kinds of coral reefs, fringing, barrier, and circular reefs, the latter known also as atolls.

Fringing reefs grow along any shore line, but the most common and interesting are those about volcanic islands in the Pacific Ocean. They are revealed by the snow-white sheets of breakers which surround the island like a snowy girdle.

Barrier reefs are found, not close to the island, like fringing reefs, but from five to fifteen miles away, in deep water. The position of the reef is shown by a snowy girdle of breakers, within which, like a charmed circle, there is calm sea in the wildest storm. Between the reef and the island there is a ship channel, often twenty or

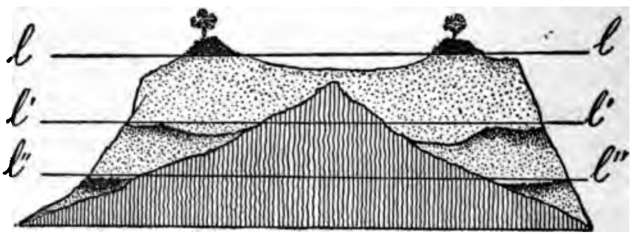
thirty fathoms deep. Through breaks or tidal ways in the reef ships enter, and find good harbor in the channel. If it were not for the action of the waves this would be all, but the beating waves form little coral islands on the reef, so that, instead of a continuous snowy girdle, it is such a girdle gemmed on the inner edge with a string of green islets.

Circular reefs or atolls are the most remarkable of all the coral formations. In this case there is no volcanic island or preexisting land of any kind apparent as a nucleus for the growth of corals. The reef seems to have been built up from abyssmal depth, in an irregular circular form, inclosing a lagoon of still water in the midst. The position of the reef is shown by a circle of snowy foam inclosing and protecting a harbor of still water. Through breaks in the reef circle ships may enter and find safe anchorage. The lagoon is ten, twenty, thirty, or even fifty miles in diameter, and thirty or forty fathoms deep.

The remarkable character of barrier and circular reefs, which seem to violate one of the most important conditions of coral growth, has led to many theories. The most probable explanation was first given by Mr. Darwin, and is known as Darwin's "subsidence theory" (Fig. 2). According to Darwin, every reef began as a

fringe, and would have remained so if the floor of the ocean had remained steady. But in all the region of barriers and atolls the ocean floor has slowly subsided, carrying all the volcanic islands with it downward. Now, if the subsidence had been more rapid than the coral ground could rise, by accumulations of débris of successive generations, then the corals would have

Fig. 2.



Ideal Section Diagram Showing the Formation of an Atoll.

l'' l'', sea level when reef was a fringe; *l' l'*, when it was a barrier, and *l l*, the present sea level.

been carried below the depth of one hundred feet and drowned. But the subsidence was not faster than the coral ground could be built up. Therefore the corals building upward, as it were for their lives, kept their heads at or near the surface. But the reef, building up *nearly* at the same place, where the volcanic island grew smaller, it is evident that the latter would be separated more and more from the reef. When

the island was down *waist deep*, the reef was a barrier; when down *head under*, it became an atoll, the reef representing *nearly* the outline of the original base of the volcanic island. We said nearly; not perfectly. The corals do not build up perpendicularly, but in a steep slope. The barrier, and much more the atoll, is therefore smaller than the original fringe. If, therefore, the subsistence continues, the atoll will grow smaller and smaller, the separate islets will close together, join each other, and finally close the lagoon. Then the lagoon will close in upon itself and form the lagoonless island, and, last of all, this also will probably disappear.

It is evident that the rate of sinking cannot have been greater than the rate of coral ground rising; otherwise the corals would have been drowned. Again, the rate of ground rising is far less than the rate of coral-prong growth. If the annual growth of all the prongs were taken, ground to powder, and strewed over the area shaded by the coral branches, it would give the annual rising of the ground. It is evident that this would be very small in comparison with the growth of the prongs. In addition to this, it must be remembered that large spaces of a coral reef are bare. Taking all these things into consideration, it has been estimated that one quarter to one half inch per annum is a large esti-

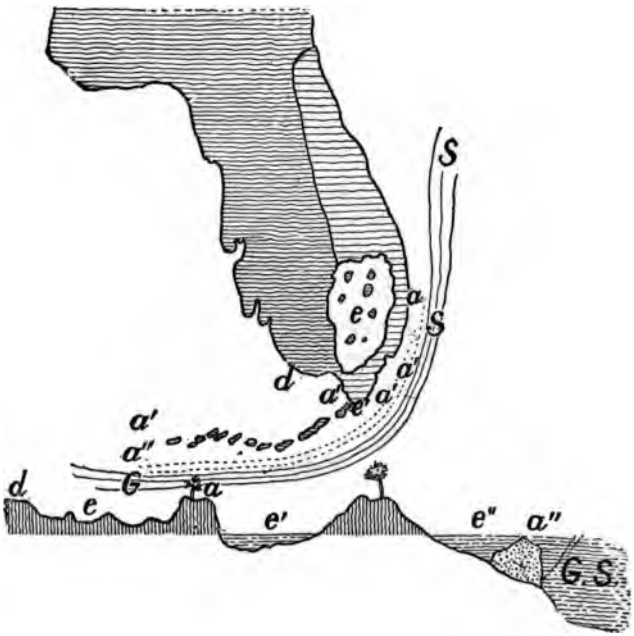
mate of rate of ground rising. The subsidence cannot be greater and may be much less than this. At this rate a subsidence of ten thousand feet would require from two hundred and fifty thousand to five hundred thousand years.

The reefs of Florida deserve separate and special treatment, not only because they are on our own coast, but also because they are in some important respects entirely peculiar: (1) In the Pacific, barrier reefs are always the result and the sign of subsidence. In Florida, on the contrary, we have barrier reefs where there has been no subsidence. (2) In the Pacific, corals do not add to the previously existing land surface; on the contrary, they only recover a small fraction of a lost land surface. But in Florida there has been apparently no loss, but a constant growth of land surface under the action of corals, assisted by waves and other agents.

The southern coast of Florida is a ridge of limestone, twelve to fifteen feet high, inclosing a swamp called the Everglades, only one to two feet above the sea level, covered with fresh water, overgrown with vegetation, and overdotted with higher spots called hummocks. Going south from the coast, the next thing that attracts attention is a line or string of limestone islands (keys), stretching in a curve

from Cape Florida to the Tortugas, a distance of one hundred and fifty miles. Between these and the southern coast is an extensive shoal, almost a mud flat, navigable only to small fish-

Fig. 3.



Map and Section of Peninsula and Keys of Florida.

***a*, coast; *a'*, keys; *a''*, reef; *e*, everglade; *e'*, shoal water; *e''*, ship channel; *G*, Gulf Stream.**

ing craft. The width of this shoal is thirty to forty miles. It is overdotted with small, low, mud islands. overgrown with mangrove trees

and entirely different from the true keys. Outside of the line of keys, and separated from it by a ship channel five or six miles wide and three to four fathoms deep, is a continuous line of living reef. On this, by the action of the waves, a few small islands have commenced to form. Outside of all sweep the deep waters of the Gulf Stream (Fig. 3).

Now, the whole area thus described is a recent coral formation, and has been added to Florida in recent geological times. The proof of this is complete.

First, on the living reef islands have just commenced to form. Some are yet only a collection of large coral fragments, the nucleus of an island. Some are more compacted by smaller fragments thrown in among the larger. Some are small but perfect islands; that is, coral, sand, and mud have been thrown upon and completely buried the large masses. But none of these are yet clothed with vegetation, much less inhabited by animals and man. Next come the larger inhabited islands of the line of keys. On cutting into these the same structure as described above is revealed. Undoubtedly these are the string of wave-formed coral islands, and here was once a line of living reef; but the corals have long ago died, because cut off from the open sea by the formation of another reef farther

out. Next comes the southern coast. Examination of this reveals the same structure precisely. Here, then, was the place of a still earlier reef.

There was, therefore, a time when the north shore of the Everglades was the southern shore of Florida. At that time the place of the present southern coast was occupied by a living reef. On this reef coral islands were formed, which gradually coalesced into a continuous line of land, the shoal water between it and the mainland was filled up, and the whole added to the mainland; the southern coast being transferred to its present position, and the shoal water, with its mangrove island, changed into the Everglades, with its hummocks. In the meantime, however, while the present southern coast was still a line of keys, another reef was formed in the place of the present line of keys, and the former have therefore died. This new reef in its turn was converted into a line of keys, which will eventually coalesce into a continuous line of land, the shoal water will be filled up and form another Everglade, with its hummocks, and the coast line be transferred to the present line of keys. But already another line is formed, and the previous line is dead; already the process of key formation has commenced. We cannot doubt that eventually, but probably only

after many thousands of years, the peninsula of Florida will extend even to the present living reef. Farther than this it cannot go, for the deep water of the Gulf Stream is close at hand, and forms its impassable boundary.

Thus, then, the extension of the peninsula of Florida in recent times has been the result of the cooperation of several agencies: (1) the Gulf Stream built up from deep sea bottom a bank, and extended it by the same process. (2) The corals took up the work by forming successive barrier reefs farther and farther south, as the necessary condition of moderate depth extended. (3) The waves then took up the work and converted the line of reef into a line of keys, and finally a line of land twelve to fifteen feet high. (4) The shoal water between the successive lines of keys and the mainland was filled up by coral débris carried inward from the reefs and keys, and southward from the previously formed land, and the mainland was thus extended to the keys.

IX

The Inside of the Earth

By ARCHIBALD GEIKIE

IT may seem, at first, hardly possible that man should know anything about the earth's interior. Think what a huge ball this globe of ours is, and how, living and moving over its surface, we are merely flies walking over a great hill. All that can be seen, from the top of the highest mountain to the bottom of the deepest mine, is not more, in comparison with the size of the whole earth, than the mere varnish on the outside of a school globe.

And yet a good deal may be learned as to what takes place within the earth. Here and there, in different countries, there are places where communication exists between the interior and the surface; and it is from such places that much of our information on this subject is derived. Volcanoes or burning mountains are among the most important of these channels of communication.

Suppose you were to visit one of these volcanoes just before what is called an "eruption." From the distance it appears as a conical moun-

tain with its top cut off. From this truncated summit a white cloud rises, but not quite such a cloud as may be seen on an ordinary hilltop, for after watching it a little time you would notice that it rises out of the top of the mountain even when the sky is cloudless. Ascending from the vegetation of the lower grounds, you would find that the slopes consist partly of loose

Fig. 1.

Mount Vesuvius as it Appears To-day.

stones and ashes, partly of rough black sheets of rock like the slags of an iron furnace. Nearer the top the ground feels hot, and puffs of steam, together with stifling vapors, come out of it here and there. At last, when the summit is reached, what seemed from below to be a level top, is seen to be in reality a great basin, with steep walls descending into the depths of the mountain. Screening your face as well as possible from the hot gases which would almost choke

you, you might creep to the edge of this basin and look down into it (Fig. 1). Far below, at the base of the rough red and yellow cliffs which form its sides, lies a pool of some liquid glowing with a white heat, though covered for the most part with a black crust like that seen on the outside of the mountain during the ascent. From this fiery pool jets of the red-hot liquid are jerked out every now and then, and harden into stone as they are cooled in the air. Showers of stones and dust are shot forth and fall back again into the caldron or down the outside of the mountain. Clouds of steam ascend from the same source to form the uprising cloud, which is seen from a great distance hanging over the mountaintop.

The caldron-shaped hollow on the summit of the mountain is called the crater. The intensely heated liquid in the sputtering, boiling pool at its bottom is melted rock or lava. The fragmentary materials—ashes, dust, cinders, and stones—are torn from liquid lava or from the hardened sides and bottom of the crater by the violence of the explosions with which the gases and steam escape.

The hot air and steam and the melted mass at the bottom of the crater show that there must be some source of intense heat underneath. And, as the heat has been coming out for hun-

dreds or even thousands of years, it must exist there in great abundance.

But it is when the volcano appears in active eruption that the power of this underground heat shows itself most markedly. For a day or two beforehand the ground around the mountain trembles. At length, in a series of violent explosions, the heart of the volcano is torn open, and perhaps its upper part is blown into the air. Huge clouds of steam roll away into the air, mingled with fine dust and red-hot stones. The heavier stones fall back again into the crater, or on the outer slopes of the mountain, but the finer ashes come out in such quantity as sometimes to darken the sky for many miles around, and to settle down over the surrounding country as a thick covering. Streams of molten lava run down the outside of the mountain and descend even to the gardens and houses at the base, burning up or overflowing whatever lies in their path. This state of matters continues for days or weeks, until the volcano exhausts itself, and then a time of comparative quiet comes when only steam, hot vapors, and gases are given off.

About eighteen hundred years ago there was a mountain near Naples shaped like a volcano, and with a large crater covered with brushwood. No one had ever seen any steam, or ashes, or

lava come from it, and the people did not imagine it to be a volcano, like some other mountains in that part of Europe. They had built villages and towns around its base, and their district, from its beauty and soft climate, used to attract wealthy Romans to build villas there. But at last, after hardly any warning, the whole of the higher part of the mountain was blown into the

Fig. 2.

Vesuvius as it Appeared before Pompeii was Destroyed.

air with terrific explosions. Such showers of fine ashes fell for miles around that the sky was as dark as midnight. Day and night the ashes and stones descended on the surrounding country; many of the inhabitants were killed, either by stones falling on them or from suffocation by the dust. When at last the eruption ceased the district which had before drawn visitors from all parts of the Old World was found to be a mere desert of gray dust and stones. Towns and

villages, vineyards and gardens, were all buried. Of the towns the two most noted, called Herculaneum and Pompeii, so completely disappeared that, although important places at the time, their very sites were forgotten, and only by accident, after the lapse of some fifteen hundred years, were they discovered. Excavations have since that time been carried on, the hardened volcanic accumulations have been removed from the two old towns, and now one can walk through the streets of Pompeii again, with their roofless dwelling-houses and shops, theaters and temples, and mark on the causeway the deep ruts worn by the carriage wheels of the Pompeians eighteen centuries ago. Beyond the walls of the now silent city rises Mount Vesuvius, with its smoking crater covering one half of the old mountain which was blown up when Pompeii disappeared.

Volcanoes, then, mark the position of some of the holes or orifices whereby heated materials from the inside of the earth are thrown up to the surface. They occur at all quarters of the globe. In Europe, besides Mount Vesuvius, which has been more or less active since its great eruption in the first century, Etna, Stromboli, Santorin, and other smaller volcanoes occur in the basin of the Mediterranean; while far to the northwest active volcanoes rise amid the

snows and glaciers of Iceland. In South America a chain of huge volcanoes stretches down the range of the Andes, that rise near the western margin of the continent. In Asia volcanoes are thickly grouped together in Java and the surrounding islands, where, in August, 1883, there occurred one of the most stupendous volcanic eruptions of recent times. From that district a line of active volcanoes stretches through Japan and the Aleutian Isles to the extremity of North America. Tracing this distribution upon the map, we observe that the Pacific Ocean is girdled round with volcanoes.

Since these openings into the interior of the earth are so numerous over the surface we may conclude that the interior is intensely hot. But other proofs of this internal heat may be gathered. In many countries hot springs rise to the surface. In some volcanic districts hot water and steam gush out at intervals with great force, and for a height of a hundred feet or more into the air. Even in England, which is a long way from any active volcano, the water of the wells of Bath is quite warm (120° Fahr.). It is known, too, that in all countries the heat increases as we descend into the earth. The deeper a mine the warmer are the rocks and the air at the bottom. If the heat continues to increase in the same proportion the rocks must

be red hot at no great distance beneath us. We must conclude, then, that this globe on which we live has a comparatively thin cool outer shell, or crust, within which the interior is intensely hot.

The explosion of volcanoes shakes the ground, sometimes with great violence. But the solid earth is affected by movements even remote from any volcano. Very delicate instruments have revealed that, though the ground beneath us seems to be perfectly steady, it is continually affected by slight tremors. When the movement becomes strong enough to be quite perceptible it is called an earthquake, which may vary from a feeble, hardly sensible trembling of the ground up to a violent concussion whereby the ground is convulsed, and even rent open; trees, rocks, and buildings are thrown down, and sometimes thousands of people are killed. Earthquakes are more particularly frequent and destructive in regions where active volcanoes exist.

Though earthquakes destroy much life and property they do not permanently alter the face of the globe so much as another kind of earth movement of a much slower and less startling nature. Some parts of the land are slowly rising. When this upheaval takes place in maritime tracts rocks that used always to be covered

by the tides come to lie wholly beyond their limits, while others, once never to be seen at all, begin one by one to show their heads above water. On the other hand, some regions are slowly sinking; piers, sea walls, and other old landmarks on the beach are one after another enveloped by the sea as it encroaches farther and higher on the land.

Even at the present day, therefore, we know that one result of the movements of the outer part or crust of the earth is to raise some regions above the level of the sea, and to increase the height of others that are already dry land. Reflecting on this process, we soon perceive that it must be by such elevations that dry land continues upon the face of the earth. If rain and frost, rivers, glaciers, and the sea, were continually and without check to wear down the surface of the land, that surface would necessarily in the end disappear, and indeed must have disappeared long ago. But, on the other hand, owing to the pushing out of some parts of the earth's surface from within, portions of the land are raised to a higher level, while parts of the bed of the sea are actually upheaved so as to form land. On the other hand, certain tracts, more particularly of the ocean floor, sink inward; the ocean basins are thus deepened and in some measure the level of the sea is thereby lowered.

This kind of oscillation has happened many times in all quarters of the globe. As already mentioned, most of our hills and valleys are formed of rocks which were originally laid down on the bottom of the sea and have been subsequently raised into land. In almost every country proofs may be found that the land has repeatedly been submerged and reelevated.

X

The Greatest Sculptor of the Rockies

Notes from MAJOR J. W. POWELL'S Report of the Exploration of the Cañons of the Colorado

IN the summer of 1867, with a small party of naturalists, students, and amateurs like myself, I visited the mountain region of Colorado Territory. The result of the summer's study was to kindle a desire to explore the cañons of the Grand, Green, and Colorado Rivers; and the next summer I organized an expedition with the intention of penetrating still farther into that cañon country. The winter of 1868–69 proved favorable to my purposes, and several excursions were made southward to the Grand, down the White to the Green River, northward to the Yampa, and around the Uinta Mountains.

The Colorado River is formed by the junction of the Grand and Green Rivers. The Grand River has its source in the Rocky Mountains, five or six miles west of Long's Peak. A group of little Alpine lakes, that receive their water directly from perpetual snow banks, discharge into a common reservoir known as Grand Lake, a beautiful sheet of water. Its quiet surface reflects towering cliffs and crags of granite on its eastern shore, and stately pines and firs stand

on its western margin. The Green River heads near Fremont's Peak in the Wind River Mountains. This river, like the last, has its sources in Alpine lakes fed by everlasting snows. Thousands of these little lakes, with deep, cold, emerald waters, are embosomed among the crags of the Rocky Mountains. These streams, born in the cold, gloomy solitudes of the upper mountain region, have a strange eventful history as they pass down through gorges, tumbling in cascades and cataracts, until they reach the hot arid plains of the Lower Colorado, where the waters that were so clear above empty as turbid floods into the Gulf of California. The Green River is larger than the Grand, and is the upper continuation of the Colorado. Including this river the whole length of the stream is about two thousand miles. The region of country drained by the Colorado and its tributaries is about eight hundred miles in length and varies from three hundred to five hundred in width, containing about three hundred thousand square miles, an area larger than all New England and the Middle States, with Maryland and Virginia added, or as large as Minnesota, Wisconsin, Iowa, Illinois, and Missouri.

There are two distinct portions of the basin of the Colorado. The lower third is but little above the level of the sea, though here and there

ranges of mountains rise to an altitude of from two to six thousand feet. This part of the valley is bounded on the north by a line of cliffs which present a bold, often vertical, step, hundreds or thousands of feet to the table-lands above. The upper two thirds of the basin rises from four to eight thousand feet above the level of the sea. This high region on the east, north, and west is set with ranges of snow-clad mountains attaining an altitude above the sea varying from eight to fourteen thousand feet. All winter long on its mountain-crested rim snow falls, filling the gorges, half burying the forests, and covering the crags and peaks with a mantle woven by the wind from the waves of the sea, a mantle of snow. When the summer's sun comes this snow melts and tumbles down the mountain sides in millions of cascades. Ten million cascade brooks unite to form ten thousand torrent creeks; ten thousand torrent creeks unite to form a hundred rivers beset with cataracts; a hundred roaring rivers unite to form the Colorado, which rolls, a mad, turbid stream, into the Gulf of California.

Consider the action of one of these streams: its source in the mountains where the snows fall; its course through the arid plain. Now if at the river's flood storms were falling on the plains its channel would be cut but little faster

than the adjacent country would be washed, and the general level would thus be preserved; but under the conditions here mentioned the river deepens its bed, as there is much corrasion and but little lateral degradation. So all the streams cut deeper and still deeper until their banks are towering cliffs of solid rock. These deep narrow gorges are called cañons.

For more than a thousand miles along its course the Colorado has cut for itself such a cañon; but at some few points where lateral streams join it the cañon is broken, and narrow transverse valleys divide it properly into a series of cañons. The Vergen, Kanab, Paria, Escalante, Dirty Devil, San Rafael, Price, and Uinta on the west, the Grand, Yampa, San Juan, and Colorado Chiquito on the east, have also cut for themselves such narrow winding gorges, or deep cañons. Every river entering these has cut another cañon; every lateral creek has cut a cañon; every brook runs in a cañon; every rill born of a shower and born again of a shower, and living only during the showers, has cut for itself a cañon; so that the whole upper portion of the basin of the Colorado is traversed by a labyrinth of these deep gorges. Owing to a eat variety of geological conditions these ons differ much in general aspect. The Rio gen, between Long Valley and the Mormon

town of Schụnesburg, runs through Pa-rú-nu-weap Cañon, often not more than twenty or thirty feet in width, and from six hundred to one thousand five hundred feet deep. Away to the north the Yampa empties into the Green by a cañon that I essayed to cross in the fall of 1868, and was baffled from day to day until the fourth had nearly passed before I could find my way down to the river. But thirty miles above its mouth this cañon ends and a narrow valley with a flood plain is found. The longest cañon through which the Colorado runs is that between the mouth of the Colorado Chiquito and the Grand Wash, a distance of two hundred and seventeen and a half miles. But this is separated from another above, sixty-five and a half miles in length, only by the narrow cañon valley of the Colorado Chiquito.

All the scenic features of this cañon land are on a giant scale, strange and weird. The streams run at depths almost inaccessible; lashing the rocks which beset their channels; rolling in rapids and plunging in falls, and making a wild music which but adds to the gloom of the solitude. The little valleys nestling along the streams are diversified by bordering willows, clumps of box elder, and small groves of cottonwood. Low mesas, dry and treeless, stretch back from the brink of the cañon, often showing

smooth surfaces of naked, solid rock. In some places, the country rock being composed of marls, the surface is a bed of loose, disintegrated material, and you walk through it as in a bed of ashes. Often these marls are richly colored and variegated. In other places the country rock is a loose sandstone, the disintegration of which has left broad stretches of drifting sand, white, golden, and vermilion. Where this sandstone is a conglomerate a paving of pebbles has been left, a mosaic of many colors, polished by the drifting sands and glistening in the sunlight.

These cañon gorges, obstructing cliffs and desert wastes, have prevented the traveler from penetrating the country, so that until the Colorado River Exploring Expedition was organized it was almost unknown. Yet enough had been seen to foment rumor, and many wonderful stories have been told in the hunter's cabin and prospector's camp. Stories were related of parties entering the gorge in boats and being carried down with fearful velocity into whirlpools, where all were overwhelmed in the abyss of waters; others of underground passages for the great river into which boats had passed never to be seen again. It was currently believed that the river was lost under the rock for several hundred miles. There were other accounts of great falls

whose roaring music could be heard on the distant mountain summits. There were many stories current of parties wandering on the brink of the cañon vainly endeavoring to reach the waters below, and perishing with thirst at last in sight of the river which was roaring its mockery in their dying ears. The Indians, too, have woven the mysteries of the cañons into the myths of their religion. Long ago there was a great and wise chief who mourned the death of his wife and would not be comforted until Ta-vwoats, one of the Indian gods, came to him and told him she was in a happier land, and offered to take him there, that he might see for himself, if upon his return he would cease to mourn. The great chief promised. Then Ta-vwoats made a trail through the mountains that intervened between that beautiful land, the balmy region in the great West, and this the desert home of the poor Nu-ma. This trail was the cañon gorge of the Colorado. Through it he led him; and when they had returned the deity exacted from the chief a promise that he would tell no one of the joys of that land, lest, through discontent with the circumstances of this world, they should desire to go to heaven. Then he rolled a river into the gorge—a mad, raging stream—that should engulf any who should attempt to enter thereby. More than once have I been warned by the In-

dians not to enter this cañon. They considered it disobedience to the gods and contempt for their authority, and believed that it would surely bring upon me their wrath.

For two years previous to the exploration I had been making some geological studies among the heads of the cañons leading to the Colorado, and a desire to explore the Grand Cañon itself grew upon me. Early in the spring of 1869 a small party was organized for this purpose. Boats were built in Chicago and transported by rail to the point where the Union Pacific Railroad crosses the Green River. With these we were to descend the Green to the Colorado, and the Colorado to the foot of the Grand Cañon.*

August 13.—We are now ready to start on our way down the Great Unknown. Our boats, tied to a common stake, are chafing each other as they are tossed by the fretful river. They ride high and buoyant, for their loads are lighter than we could desire. We have a month's rations remaining. The flour has been resifted through the mosquito net sieve; the spoiled bacon has been dried and the worst of it boiled;

* Major Powell's expedition left Green River City May 24, 1869. Several of the cañons already referred to were thoroughly explored. The trip ended with the exciting and often perilous voyage through the Grand Cañon. An abridged account of that voyage is here given in Major Powell's own fascinating style.

the few pounds of dried apples have been spread in the sun and reshrunken to their normal bulk; the sugar is all melted and gone on its way down the river; but we have a large sack of coffee. The lightening of the boats has this advantage: they will ride the waves better, and we shall have but little to carry when we make a portage.

We are three quarters of a mile in the depths of the earth, and the great river shrinks into insignificance as it dashes its angry waves against the walls and cliffs that rise to the world above; they are but puny ripples and we but pygmies running up and down the sands, or lost among the bowlders. We have an unknown distance yet to run, an unknown river yet to explore. What falls there are we know not; what rocks beset the channel we know not; what walls rise over the river we know not. Ah, well, we may conjecture many things. The men talk as cheerfully as ever; jests are bandied about freely this morning; but to me the cheer is somber and the jests are ghastly. With some eagerness and some anxiety and some misgiving we enter the cañon below and are carried along by the swift water to walls which rise to its very edge. They have the same structure that we noticed yesterday—tiers of irregular shelves below, and above these steep slopes to the foot of marble cliffs.

We run six miles in a little more than half an hour, and emerge into a more open portion of the cañon, where high hills and ledges of rocks intervene between the river and the distant walls. Just at the head of this open place the river runs across a dike; that is, a fissure in the rocks, open to depths below, has been filled with erupted matter, and this on cooling was harder than the rocks through which the crevice was made, and when these were washed away the harder volcanic matter remained as a wall, and the river has cut a gateway through it several hundred feet high, and as many wide. As it crosses the wall there is a fall below and a bad rapids filled with bowlders of trap; so we stop to make a portage. Then on we go, gliding by hills and ledges with distant walls in view; sweeping past sharp angles of rock; stopping at a few points to examine rapids which we find can be run, until we have made another five miles, when we land for dinner. Then we let down with lines over a long rapids and start again. Once more the walls close in, and we find ourselves in a narrow gorge, the water again filling the channel and very swift. With great care and constant watchfulness we proceed, making about four miles this afternoon, and camp in a cave.

August 14.—After breakfast we enter on the waves. At the very introduction it inspires

awe. The cañon is narrower than we have ever before seen it; the water is swifter; there are but few broken rocks in the channel, but the walls are set on either side with pinnacles and crags; and sharp, angular buttresses, bristling with wind and wave-polished spires, extend far out into the river. About eleven o'clock we hear a great roar ahead and approach it very cautiously. The sound grows louder and louder as we run, and at last we find ourselves above a long broken falls, with ledges and pinnacles of rock obstructing the river. There is a descent of perhaps seventy-five or eighty feet in a third of a mile, and the rushing waters break into great waves on the rocks and lash themselves into a mad, white foam. We can land just above, but there is no foothold on either side by which we can make a portage. It is nearly a thousand feet to the top of the granite, so it will be impossible to carry our boats around. There is no hesitation. We step into our boats, push off, and away we go, first on smooth but swift waters, then we strike a glassy wave and ride to its top, down again into the trough, up again on a higher wave, and down and up on waves, higher and still higher, until we strike one just as it curls back, and a breaker rolls over our little boat. Still on we speed, shooting past projecting rocks, till the little boat is caught in a whirlpool and

spun around several times. At last we pull out again into the stream, and now the other boats have passed us. Hurled back from a rock, now on this side, now on that, we are carried into an eddy, into which we struggle for a few minutes, and are then out again, the breakers still rolling over us. Our boat is unmanageable, but she cannot sink, and we drift down another hundred yards through breakers—how, we scarcely know. The walls now are more than a mile in height—a vertical distance difficult to appreciate. A thousand feet of this is up through granite crags, then steep slopes and perpendicular cliffs rise one above another to the summit. The gorge is black and narrow below, red and gray and flaring above, with crags and angular projections on the walls, which, cut in many places by side cañons, seem to be a vast wilderness of rocks. Down in these grand, gloomy depths we glide, ever listening, for the mad waters keep up their roar; ever watching, ever peering ahead, for the narrow cañon is winding and the river is closed in so that we can see but a few hundred yards, and what there may be below we know not; but we listen for falls, and watch for rocks, or stop now and then in the bay of a recess to admire the gigantic scenery. And ever as we go there is some new pinnacle or tower, some crag or peak, some distant view of the upper

plateau, some strange rock, or some deep narrow side cañon.

August 15.—Clouds are playing in the cañon to-day. Sometimes they roll down in great masses, filling the gorge with gloom; sometimes they hang above from wall to wall and cover the cañon with a roof of impending storm; and we can peer long distances up and down this cañon corridor with its cloud roof overhead, its walls of black granite, and its river bright with the sheen of broken waters. Then a gust of wind sweeps down a side gulch, and, making a rift in the clouds, reveals the blue heavens, and a stream of sunlight pours in. Then the clouds drift away into the distance and hang around crags and peaks and pinnacles and towers and walls and cover them with a mantle that lifts from time to time and sets them all in sharp relief. Then baby clouds creep out of side cañons, glide around points, and creep back again into more distant gorges. Then clouds set in strata cross the cañon with intervening vista views to cliffs and rocks beyond. The clouds are children of the heavens, and when they play among the rocks they lift them to the region above. It rains. Rapidly little rills are formed above and these soon grow into brooks, and the brooks grow into creeks, and tumble over the walls in innumerable cascades, adding their wild music to the

roar of the river. When the rain ceases the rills, brooks, and creeks run dry. The waters that fall during a rain on these steep rocks are gathered at once into the river; they could scarcely be poured in more suddenly if some vast spout ran from the clouds to the stream itself. When a storm bursts over the cañon a side gulch is dangerous, for a sudden flood may come and the inpouring waters will raise the river so as to hide the rocks before your eyes.

August 18.—While the men are at work making portages I climb up the granite to its summit, and go away back over the rust-colored sandstones and greenish yellow shales to the foot of the marble wall. I climb so high that the men and boats are lost in the black depths below and the dashing river is a rippling brook; and still there is more cañon above than below. All about me are interesting geological records. The book is opened, and I can read as I run. All about me are grand views, for the clouds are playing again in the gorges. But somehow I think of the nine days' rations and the bad river, and the lesson of the rock and the glory of the scene is but half seen.

August 20.—The characteristics of the cañon change this morning. The river is broader, the walls more sloping, and composed of black slates

that stand on edge. These nearly vertical slates are washed out in places—that is, the softer beds are washed out between the harder, which are left standing. In this way curious little alcoves are formed in which are quiet bays of water, but on a much smaller scale than the great bays and buttresses of the marble cañon. The river is still rapid, and we stop to let down with lines several times, but make greater progress, as we run ten miles. We camp on the right bank. Here on a terrace of trap we discover another group of ruins. There was evidently quite a village on this rock. Again we find kneeling stones and much broken pottery, and up in a little natural shelf in the rock, back of the ruins, we find a globular basket that would hold, perhaps, a third of a bushel. It is badly broken, and as I attempt to take it up it falls to pieces. There are many beautiful flint chips, as if this had been the home of an old arrow maker.

August 23.—Our way to-day is again through marble walls. Now and then we pass for a short distance through patches of granitelike hills thrust up into the limestone. Sometimes a cottonwood tree grows over the water. I come to one beautiful fall of more than one hundred and fifty feet, and climb around it to the right on the broken rocks. Still going up I find the cañon narrowing very much, being but fifteen

or twenty feet wide; yet the walls rise on either side many hundreds of feet, perhaps thousands. In some places the stream has not excavated its channel down vertically through the rocks, but has cut obliquely, so that one wall overhangs the other. In other places it is cut vertically above and obliquely below, or obliquely above and vertically below, so that it is impossible to see out overhead. Just after dinner we pass a stream on the right which leaps into the Colorado by a direct fall of more than a hundred feet, forming a beautiful cascade. There is a bed of very hard rock above, thirty or forty feet in thickness, and much softer beds below. The hard beds above project many yards beyond the softer, which are washed out, forming a deep cave behind the fall, and the stream pours through a narrow crevice above into a deep pool below. Around on the rocks in the cavelike chamber are set beautiful ferns with delicate fronds and enameled stocks. The little frondlets have their points turned down to form spore cases. It has very much the appearance of the maidenhair fern, but is much larger. This delicate foliage covers the rocks all about the fountain and gives the chamber great beauty.

August 25.—We make twelve miles this morning, when we come to monuments of lava stand-

ing in the river, low rocks mostly, but of shafts more than a hundred feet high. We have no difficulty as we float along, and I am able to observe the wonderful phenomena connected with this flood of lava. The cañon was doubtless filled to a height of twelve or fifteen hundred feet, perhaps by more than one flood. This would dam the water back; and in cutting through this great lava bed a new channel has been formed, sometimes on one side, sometimes on the other. The cooled lava, being of firmer texture than the rocks of which the walls are composed, remains in some places; in others a narrow channel has been cut, leaving a line of basalt on either side. It is possible that the lava cooled faster on the sides against the walls, and that the center ran out; but of this we can only conjecture. There are other places where almost the whole of the lava is gone, patches of it only being seen where it has cut on the walls. As we float down we can see that it ran out into side cañons. In some places this basalt has a fine, columnal structure, often in concentric prisms, and masses of these concentric columns have coalesced. In some places when the flow occurred the cañon was probably at about the same depth as it is now, for we can see where the basalt has rolled out on the sand, and, what seems curious to me, the sands are not melted

or metamorphosed to any appreciable extent. In places the bed of the river is of sandstone or limestone, in other places of lava, showing that it has all been cut out of again where the sandstones and limestones appear; but there is a little yet left where the bed is of lava. What a conflict of water and fire there must have been here! Just imagine a river of molten rock running down into a river of melted snow. What a seething and boiling of the waters; what clouds of steam rolled into the heavens!

Thirty-five miles to-day. Hurrah!

August 26.—Since we left the Colorado Chiquito we have seen no evidences that the tribe of Indians inhabiting the plateaus on either side ever come down to the river; but about eleven o'clock to-day we discover an Indian garden at the foot of the wall on the right, just where a little stream with a narrow flood-plain comes down through a side cañon. Along the valley the Indians have planted corn, using the water which bursts out of the spring at the foot of the cliff for irrigation. The corn is looking quite well, but is not sufficiently advanced to give us roasting ears; but there are some nice green squashes. What a supper we make; unleavened bread, green squash sauce, and strong coffee! We have been for a few days on half rations, *but we have no stint of roast squash!*

August 27.—About eleven o'clock we come to a place in the river where it seems much worse than any we have yet met in all its course. A little creek comes down from the left. We land first on the right and clamber up over the granite pinnacles for a mile or two, but can see no way by which we can let down, and to run it would be sure destruction. After dinner we cross to examine it on the left. High above the river we can walk along the top of the granite, which is broken off at the edge and set with crags and pinnacles so that it is very difficult to get a view of the river at all. In my eagerness to reach a point where I can see the roaring fall below I go too far on the wall, and can neither advance nor retreat. I stand with one foot on a little projecting rock and cling with my hands fixed in a little crevice. Finding I am caught here, suspended four hundred feet above the river, into which I should fall if my footing fails, I call for help. The men come and pass me a line, but I cannot let go of the rock long enough to take hold of it. Then they bring two or three of the largest oars. All this takes time which seems very precious to me; but at last they arrive. The blade of one of the oars is pushed into a little crevice in the rock beyond me in such a manner that they can hold me pressed against the wall. Then another is fixed in such

a way that I can step on it, and thus I am extricated.

August 29.—The relief from danger and the joy of success are great. When he who was chained by wounds to a hospital cot until his canvas tent seems like a dungeon cell, until the stench of festering wounds and anæsthetic drugs has filled the air with its loathsome burden, at last goes out into the open field, what a world he sees! How beautiful the sky; how bright the sunshine; what floods of delirious music pour from the throats of birds; how sweet the fragrance of earth and tree and blossom! The first hour of convalescent freedom seems rich recompense for all—pain, gloom, terror. Something like this are the feelings we experience to-night. Ever before us has been an unknown danger, heavier than immediate peril. Every waking hour passed in the Grand Cañon has been one of toil. We have watched with deep solicitude the steady disappearance of our scant supply of rations, and from time to time have seen the river snatch a portion of the little left while we were ahungered. And danger and toil were endured in those gloomy depths where ofttimes the clouds hid the sky by day and but a narrow zone of stars could be seen at night. Only during the few hours of deep sleep, consequent on hard labor, has the roar of the waters

been hushed. Now the danger is over; now the toil is ceased; now the gloom is disappeared; now the firmament is bounded only by the horizon; and what a vast expanse of constellations can be seen! The river rolls by us in silent majesty; the quiet of the camp is sweet; our joy is almost ecstasy. We sit till long after midnight talking of the Grand Cañon, talking of home.

XI

Where Nothing Happens

Adapted from HOWE'S *Descriptive Astronomy*, by permission of Silver, Burdett & Co.

IT is a land of death. The sky is a pall of black studded with stars by day as well as by night. The rising sun, unheralded by the beautiful sky tints which accompany the dawn on earth, darts its garish beams athwart the desolate landscape, causing the lofty peaks to cast long shadows which vie with the sky in blackness. No bird song greets him; there is no rustle of a breeze, or plash of a brook, or murmur of an ocean. Should "lips quiver and tongues essay to speak" no sound from them would break the eternal silence. Dark pits innumerable yawn on every hand. The silvery rims of the mighty craters encircle abysses of darkness. As the sun slowly rises in the sky the fierce chill of the departing night is slowly mitigated; but no manlike being welcomes returning warmth.

The earth hangs continually in mid-heaven, waxing from crescent to full and waning again, swiftly spinning on its axis and bringing into view an ever-shifting panorama of cloud and continent and ocean. No star forgets to shine; the weird glory of the solar corona and the fan-

tastic protuberances can be seen in all their beauty by screening off the direct rays of the sun. The Milky Way girdles the sky, bejeweled with thousands of glittering orbs. The eye is enchanted by the glories above, though the mind shrinks from the contemplation of the desolation all about. After fourteen terrestrial days have elapsed the long shadows stretch themselves eastward, the sun slowly sinks beneath the western horizon, and the night with its terrible rigors of cold comes on apace. Such is a lunar day.

What are the causes of so marvelous a state of affairs? First of all, the moon has little or no atmosphere. It has been demonstrated that the atmosphere, if it exists, is extremely rare, the pressure not exceeding a thousandth that at the earth's surface. When a star is occulted it ought, if there were a lunar atmosphere one tenth as dense as that of the earth, to suffer a change of brightness and color when close to the moon's edge or limb; further, as one sees the sun after it has really set, on account of refraction, so the time of the star's disappearance would be much retarded by the refraction of the lunar atmosphere, and its reappearance would be accelerated. Twilight causes an illumination of the terrestrial landscape for some time after the sun has set. No marked illumination

of this sort has been seen at any point on the moon.

The lunar spectrum is identical with the solar; this shows that the sun's rays when reflected from the moon suffer no noticeable absorption by its atmosphere.

What can be on the side of the moon which we never see we cannot affirm, but there is no reason to think it different from the face presented to us. Any water existing as lakes or rivers would be visible if only half a mile in diameter. Because of the intense cold, without doubt water would, if present, be in the form of snow or ice, but no indications of either exist. That the moon was once a molten mass seems almost certain. The craters are sometimes called the moon's volcanoes, but they give no sign of present activity. Any molten matter on cooling would be broken open in spots by the confined gases, the molten matter exuding from these openings would produce such miniature volcanoes as are seen in the floors of the great craters.

At the time of full moon certain rays or streaks diverge in all directions from some of the craters; they seem to be neither elevations nor depressions, and they go over craters and through valleys as though painted on the lunar landscape. No satisfactory explanation of these has ever

been given. The appearance of a given crater may change very materially in an hour, because of the shifting of the shadow. This and other slight causes of disturbance arising in our atmosphere have been assumed as evidences of changes where none have really taken place. There is not the slightest evidence of any volcanic activity. The only events possible are landslips and the emanation of vapors from the crust.

Since nothing happens there let us imagine some things that might happen. These we can estimate by comparison with the earth.

Because of its small size the force of gravity is but one sixth that of the earth's, so that a rifle bullet would "carry" one hundred miles, and a very ordinary athlete could jump a fence of one hundred feet high.

Because the moon "has no clothes," or is not protected by an atmosphere, its temperature varies from below freezing to a cold which we cannot imagine. Our atmosphere acts as a blanket to keep us warm. The sun's rays pass through it and warm the earth, but when the earth begins to again radiate the heat during our night of twelve hours the air acts as a check. On high mountains, where the air blanket is much thinner, the rigors of eternal winter reign. The atmosphere of the moon could not in the

slightest degree restrain the radiation throughout its night of fourteen days' duration.

The most stupendous work done by the moon is the rise of the tides, of which it is the chief cause. Though it cannot be the scene of stirring events it can be the cause of many and various activities on the earth. The flood tide lifts many a mighty ship each day over the bar at the harbor mouth. Merchantmen are carried on the tide from the mouth of the Thames up to the wharves of London. The tides scour out the harbor of New York twice each day, carrying away the dirt and filth which a great city empties there. The enormous power of the tides is in a few instances utilized to run mills, and some day it may be stored as electricity to be used whenever wanted. The variation of the moon's appearance from day to day, together with the change in its time of rising, gives rise to the idea of its instability and uncertainty; yet many a mariner's watch is reset from observations of its occultation of some bright star. From data in the *Nautical Almanac* the exact time of an occultation for a given place may be computed. The chronometer's reading is noted at the time of disappearance of the star. By comparing this reading with the computed time the error is corrected.

The most interesting of the phenomena connected with the moon are its eclipses. Few

people realize that the moon, smaller than either the earth or the sun, eclipses the sun oftener than it is itself eclipsed. Yet such is the case. There may be but two eclipses of the moon in the same year when five eclipses of the sun occur. The eclipses of the moon being visible over a larger territory are more often observed. A total eclipse is perhaps the grandest of natural phenomena. At the beginning of the eclipse the moon appears to eat away the edge of the sun's disk, forming a notch. This notch increases in size until it finally covers the entire sun. Just before the sun is covered the landscape assumes an unearthly hue. Awe seizes the beholder; one sometimes sees the moon's shadow advancing through the air with terrifying swiftness, as if to smite him. In a few seconds it reaches him, and the last ray of sunlight is gone; the planets and bright stars appear. Around the black ball now hanging in the sky the pearly corona flashes out in all its weird beauty. At its base glow the prominences, like rubies set in pearl. Men's faces grow ghastly. The silence of death is upon the beholders. Soon there is a sudden flash of sunlight at the western limb of the moon; the corona and prominences fade apace. The gloom is overpast, and silence gives place to exclamations of wonder and delight.

XII

The Path of a Smile

Adapted from CHARLES DARWIN'S *Expression of the Emotions in Man and Animals*

THE movements of expression in the face and body are in themselves of much importance to our welfare. They serve as the first means of communication between the mother and her infant; she smiles approval, and thus encourages her child in the right path, or frowns disapproval. The movements of expression give vividness and energy to our spoken words. They reveal the thoughts and intentions of others more truly than do words, which may be falsified. Whatever amount of truth the so-called science of physiognomy may contain appears to depend, as Haller long ago remarked, on different persons bringing into frequent use different facial muscles according to their dispositions; the development of these muscles being thus increased, and the lines or furrows on the face, due to their habitual contraction, being thus rendered deeper and more conspicuous. The free expression by outward signs of an emotion intensifies it. He who gives way to an emotion increases his capacity for similar expressions.

It has often struck me as a curious fact that so many shades of expression are instantly recognized without any conscious process of analysis on our part. No one, I believe, can clearly describe a cheerful or benign expression; yet many observers are unanimous that these expressions can be recognized in the various races of man.

Laughter seems primarily to be the expression of mere joy or happiness. We clearly see this in children at play, who are almost incessantly laughing. With young persons past childhood, when they are in high spirits, there is always much meaningless laughter. The laughter of the gods is described by Homer as "the exuberance of their celestial joy after their daily banquet." A man smiles, and smiling, as we shall see, graduates into laughter, at meeting an old friend in the street, as he does at any trifling pleasure, such as smelling a sweet perfume. Laura Bridgman, from her blindness and deafness, could not have acquired any expression through imitation, yet when a letter from a beloved friend was communicated to her by gesture language, "she laughed and clapped her hands, and the color mounted to her cheeks."

With grown-up persons laughter is excited by causes considerably different from those which suffice during childhood; but this remark hardly applies to smiling. Laughter in this

respect is analogous with weeping, which with adults is almost confined to mental distress, while with children it is excited by bodily pain or any suffering, as well as by fear or rage. Many curious discussions have been written on the causes of laughter in grown-up persons. The subject is extremely complex. Something incongruous or unaccountable, exciting surprise and some sense of superiority in the laugher, who must be in a happy frame of mind, seems to be the commonest cause. If the mind is strangely excited by pleasurable feelings, and any little unexpected event or thought occurs, then, as Mr. Herbert Spencer remarks, "a large amount of nervous energy, instead of being allowed to expend itself in producing an equivalent amount of new thoughts and emotions, is suddenly checked in its flow." "The excess must discharge itself in some other direction, and there results an efflux through the motor nerves to various classes of the muscles, producing the half-convulsive actions we term laughter." An observation bearing on this point was made by a correspondent during the recent siege of Paris, namely, that the German soldiers, after strong excitement from exposure to extreme danger, were particularly apt to burst into loud laughter at the smallest joke. So, again, when young children are just beginning to cry an unexpected

event will sometimes suddenly turn their crying into laughter, which apparently serves equally well to expend their superfluous energy.

The imagination is sometimes said to be tickled by a ludicrous idea; and this so-called tickling of the mind is curiously analogous with that of the body. Everyone knows how immoderately children laugh and how their whole bodies are convulsed when they are tickled. Yet laughter from a ludicrous idea, though involuntary, cannot be called a strictly reflex action. In this case, and in laughter from being tickled, the mind must be in a pleasurable state; a young child if tickled by a strange man would scream with fear. The parts of the body which are most easily tickled are those which are not commonly touched, such as the armpits or between the toes, or parts such as the soles of the feet, which are habitually touched by a broad surface; but the surface on which we sit offers a marked exception to the rule. From the fact that a child can hardly tickle itself, or in a much less degree than when tickled by another person, it seems that the precise point to be touched must not be known; so with the mind, something unexpected—a novel or incongruous idea which breaks through an habitual train of thought—appears to be the strong element in the ludicrous.

During laughter the mouth is opened more or

less widely, with the corners drawn much backward, as well as a little upward; and the upper lip is somewhat raised. The drawing back of the corners is best seen in moderate laughter, and especially in a broad smile—the latter epithet showing how the mouth is widened. In the accompanying figures on the opposite page different degrees of moderate laughter and smiling have been photographed. Under the emotion of joy, the mouth is acted on exclusively by the great zygomatic muscles, which serve to draw the corners backward and upward; but judging from the manner in which the upper teeth are always exposed during laughter and broad smiling, as well as from my own sensations, I cannot doubt that some of the muscles running to the upper lip are likewise brought into moderate action. The upper and lower orbicular muscles of the eyes are at the same time more or less contracted; and there is an intimate connection between these and some of the muscles running to the upper lip. Henle remarks, on this head, that when a man closely shuts one eye he cannot avoid retracting the upper lip on the same side; conversely, if anyone will place his finger on his lower eyelid, and then uncover his upper incisors as much as possible he will feel, as his upper lip is drawn strongly upward, that the muscles of the lower eyelid contract.

By the drawing backward and upward of the corners of the mouth, through the contraction of the great zygomatic muscles, and by the raising of the upper lip the cheeks are drawn upward. Wrinkles are thus formed under the eyes, and, with old people, at their outer ends; and these are highly characteristic of laughter or smiling. As a gentle smile increases into a strong one, or into a laugh, everyone may feel and see, if he will attend to his own sensations and look at himself in a mirror, that as the upper lip is drawn up and the lower orbiculars contract, the wrinkles in the lower eyelids and those beneath the eyes are much strengthened or increased. At the same time, as I have repeatedly observed, the eyebrows are slightly lowered, which shows that the upper as well as the lower orbiculars contract at least to some degree, though this passes unperceived, as far as our sensations are concerned.

As in laughing and broadly smiling the cheeks and upper lip are much raised, the nose appears to be shortened, and the skin on the bridge becomes finely wrinkled in transverse lines, with other oblique longitudinal lines on the sides. The upper front teeth are commonly exposed. A well-marked fold is formed, which runs from the wing of each nostril to the corner of the mouth; and this fold is often double in old persons.

A bright and sparkling eye is as characteristic of a pleased or amused state of mind as is the retraction of the corners of the mouth and upper lip, with the wrinkles thus produced. Under extreme laughter the eyes are too much suffused with tears to sparkle, but the moisture squeezed out of the glands during moderate laughter or smiling may aid in giving them luster; though this must be of altogether subordinate importance, as they become dull from grief, though they are then often moist. Their brightness seems to be chiefly due to their tenseness, owing to the contraction of the orbicular muscles and to the pressure of the raised cheeks. But according to Dr. Piderit, who has discussed this point more fully than any other writer, the tenseness may be largely attributed to the eyeballs becoming filled with blood and other fluids, from the acceleration of the circulation consequent on the excitement of pleasure. Any cause which lowers the circulation deadens the eye.

To return to the sounds produced during laughter. We can see vaguely how the utterance of sounds of some kind would naturally become associated with a pleasurable state of mind. But why the sounds which man utters when he is pleased have the peculiar reiterated character of laughter we do not know. Nevertheless we can see that they would naturally be

as different as possible from the screams or cries of distress; and as in the production of the latter the expirations are prolonged and continuous, with the inspirations short and interrupted, so it might perhaps have been expected with the sounds uttered from joy that the expirations would have been short and broken with the inspirations prolonged; and this is the case.

It is an equally obscure point why the corners of the mouth are retracted and the upper lip raised during ordinary laughter. The mouth must not be opened to its utmost extent, for when this occurs during a paroxysm of excessive laughter hardly any sound is emitted. But as a full volume of sound has to be poured forth the orifice of the mouth must be large; and it is perhaps to gain this end that the corners are retracted and the upper lip raised. Although we can hardly account for the shape of the mouth during laughter which leads to wrinkles being formed beneath the eyes, nor for the peculiar reiterated sound of laughter, nor for the quivering of the jaws, nevertheless we may infer that all these effects are due to some common cause. For they are all characteristic and expressive of a pleased state of mind.

A graduated series can be followed from violent, to moderate laughter, to a broad smile, to a gentle smile, and to the expression of mere

cheerfulness. During excessive laughter tears are often freely shed. Hence, as formerly remarked, it is scarcely possible to point out any difference between the tear-stained face of a person after a paroxysm of excessive laughter and after a bitter crying fit. It is probably due to the close similarity of the spasmodic movements caused by these widely different emotions that hysteric patients alternately cry and laugh with violence, and that young children sometimes pass suddenly from the one to the other state. Mr. Swinhoe informs me that he has often seen the Chinese, when suffering from deep grief, burst out into hysterical fits of laughter.

I was anxious to know whether tears were freely shed during excessive laughter by most of the races of men, and I hear from my correspondents that this is the case. One instance was observed with the Hindus, and they themselves said that it often occurred. So it is with the Chinese. The women of a wild tribe of Malays in the Malacca peninsula sometimes shed tears when they laugh heartily, though this seldom occurs. With the Dayaks of Borneo it must frequently be the case, at least with the women, for I hear from the Rajah C. Brooke that it is a common expression with them to say, "We nearly made tears from laughter." The

aborigines of Australia express their emotions freely, and they are described by my correspondents as jumping about and clapping their hands for joy, and as often roaring with laughter. No less than four observers have seen their eyes freely watering on such occasions; and in one instance the tears rolled down their cheeks.

In southern Africa, with two tribes of Kaffirs, especially with the women, their eyes often fill with tears during laughter. Gaika, the brother of the chief Sandilli, answers my query on this head with the words, "Yes, that is their common practice." Sir Andrew Smith has seen the painted face of a Hottentot woman all furrowed with tears after a fit of laughter. In northern Africa, with the Abyssinians, tears are secreted under the same circumstances. Lastly, in North America the same fact has been observed in a remarkably savage and isolated tribe, but chiefly with the women; in another tribe it is observed only on a single occasion.

Excessive laughter, as before remarked, graduates into moderate laughter. In this latter case the muscles round the eyes are much less contracted, and there is little or no frowning. Between a gentle laugh and a broad smile there is hardly any difference except that in smiling no reiterated sound is uttered, though a single rather strong expiration or slight noise—a rudi-

ment of a laugh—may often be heard at the commencement of a smile. On a moderately smiling countenance the contraction of the upper orbicular muscles can still just be traced by a slight lowering of the eyebrows. From the broadest smile we pass by the finest steps into the gentlest one. In this latter case the features are moved in a much less degree, and much more slowly, and the mouth is kept closed. The curvature of the nasolabial furrow is also slightly different in the two cases. We thus see that no abrupt line of demarkation can be drawn between the movement of the features during the most violent laughter and the very faint smile.

A smile, therefore, may be said to be the first stage in the development of a laugh. But a different and more probable view may be suggested, namely, that the habit of uttering loud reiterated sounds from a sense of pleasure first led to the retraction of the corners of the mouth and of the upper lip, and to the contraction of the orbicular muscles; and that now, through association and long-continued habit, the same muscles are brought into slight play whenever any cause excites in us a feeling which, if stronger, would have led to laughter, and the result is a smile.

Whether we look at laughter as the full de-

velopment of the smile, or, as is more probable, at a gentle smile as the last trace of a habit, firmly fixed during many generations, of laughing whenever we are joyful, we can follow in our infants the gradual passage of the one into the other. It is well known to those who have the charge of young infants that it is difficult to feel sure when certain movements are really expressive; that is, when they really smile. Hence I carefully watch my own infants. One of them at the age of forty-five days, and being at the time in a happy frame of mind, smiled; that is, the corners of the mouth were retracted, and simultaneously the eyes became decidedly bright. I observed the same thing on the following day; the child was not quite well, and there was no trace of a smile; and this renders it probable that the previous smiles were real. Eight days subsequently and during the next succeeding week it was remarkable how his eyes brightened whenever he smiled, and his nose became at the same time transversely wrinkled. This was now accompanied by a little bleating noise which perhaps represented a laugh. At the age of one hundred and thirteen days these little noises, which were always made during expiration, assumed a slightly different character, and were more broken and interrupted, as in sobbing; and this was certainly incipient

laughter. The change in tone seemed to me at the time to be connected with the greater lateral extension of the mouth as the smiles became broader.

In the second infant the first real smile was observed at about the same age, namely, forty-five days, and in a third at a somewhat earlier age. The second infant when sixty-five days old smiled much more broadly and plainly than did the one first mentioned at the same age, and even at this early age uttered noises very like laughter. In this gradual acquirement by infants of the habit of laughter we have a case analogous to that of weeping. As practice is requisite with the ordinary movements of the body, such as walking, so it seems to be in laughing and weeping.

According to Sir C. Bell, "In all the exhilarating passions the eyebrows, eyelids, the nostrils, and the angles of the mouth are raised. In the depressing passions it is the reverse." In joy the face expands, in grief it lengthens. Whether the principle of antithesis has here come into play in producing these opposite expressions, in aid of the direct causes which have been specified and which are sufficiently plain, I will not pretend to say. With all the races of man the expression of good spirits appears to be the same, and is easily recognized.

Laughter is suppressed by the firm contraction of the orbicular muscles of the mouth, which prevents the great zygomatic and other muscles from drawing the lips backward and upward. The lower lip is also sometimes held by the teeth, and this gives a roguish expression to the face, as was observed with the blind and deaf Laura Bridgman. The great zygomatic muscle is sometimes variable in its course, and I have seen a young woman in whom the muscles which depress the corners of the mouth were brought into strong action in suppressing a smile; but this by no means gave to her countenance a melancholy expression, owing to the brightness of her eyes. Laughter is frequently employed in a forced manner to conceal or mask some other state of mind, even anger. We often see persons laughing in order to conceal their shame or shyness. In the case of derision a real or pretended smile or laugh is often blended with the expression proper to contempt, and this may pass into angry contempt or scorn. In such cases the meaning of the laugh or smile is to show the offending person that he excites only amusement.

Although the emotion of love—for instance, that of a mother for her child—is one of the strongest of which the mind is capable, it can hardly be said to have any proper or peculiar

means of expression. No doubt, as affection is a pleasurable sensation, it generally causes a gentle smile and some brightening of the eyes. A strong desire to touch the beloved person is commonly felt; and love is expressed by this means more plainly than any other. Hence we long to clasp in our arms those we tenderly love. We probably owe this desire to inherited habit, in association with the nursing and tending of our children, and with the mutual caresses of lovers.

With respect to joy, its natural and universal expression is laughter; and with all the races of man loud laughter leads to the secretion of tears more freely than does any other cause excepting distress. The suffusion of the eyes with tears, which undoubtedly occurs under great joy, though there is no laughter, can, as it seems to me, be explained through habit and association. Nevertheless it is not a little remarkable that sympathy with the distresses of others should excite tears more freely than our own distress; and this is certainly the case. Many a man, from whose eyes no suffering of his own could wring a tear, has shed tears at the sufferings of a beloved friend. It is still more remarkable that sympathy with the happiness or good fortune of those whom we tenderly love should lead to the same result, while a similar happiness felt by ourselves would leave the eyes dry.

We should, however, bear in mind that the long-continued habit of restraint, which is so powerful in checking the free flow of tears from bodily pain, has not been brought into play in preventing a moderate effusion of tears in sympathy with the sufferings or happiness of others.

XIII

Wonders of the World's Waste

By GEORGE WILLIAM JORDAN, by permission of the Curtis Publishing Company

ONE of the signal advances made by this many-sided century has been in invention and industry. In no way has this progress been more vividly shown than in its conquest of waste. Nature, despite her marvelous prodigality, when closely studied, is seen to waste nothing, to use and to reuse all things in unending cycles of activity. At the miraculous feeding of the five thousand, when loaves and fishes were multiplied without stint, it was commanded that the people should gather up the fragments that remained, that nothing might be lost. This lesson, carried out by science as an instructive lesson in economy, contains most interesting instances.

Marvelous Uses of Coal Tar.

No tale in *The Arabian Nights*, no story of the wondrous treasures taken by mystic power from magic nutshells, surpasses what science is doing to-day. Science, the wizard of the century, reaches with his fairy wand the black, viscid coal tar from the gas retorts, and coal becomes not only a source of light and heat, but an

arsenal of colors, a buffet of dainty tastes, a medicine chest for suffering humanity, a storehouse of new foods and exquisite perfumes, a source of powerful explosives for war, and so many other miraculous powers that the telling challenges credence. From the one hundred and forty pounds of gas tar in a ton of coal science to-day makes aniline dyes, numbering over two thousand distinct shades, many of them being of exquisite delicacy, so that vegetable dyes are almost displaced. Of medicines, antiseptics, hypnotics, and fever-allaying preparations it furnishes quinine, antipyrine, atropine, morphine, exalgine, somnal, salol, chloralamide, hypnol, and a host of others. It furnishes perfumes — heliotropine, clove, queen of the meadows, cinnamon, bitter almonds, vanillin, camphor, wintergreen, and thymol. It has given to the world bellite and picrite, two powerful explosives. It supplies flavoring extracts that duplicate the taste of currants, raspberries, pepper, vanilla, etc. It is the housekeeper's ally, with benzine and naphtha, the insecticides. It supplies the farmer with ammoniacal fertilizers. It has given to the photographer his two developers, hydroquinone and eikonogen. It makes the anatomist its debtor for a most wonderful stain for tissues. It contains the substance which tints the photographer's lens. It yields

paraffin, creosote, pitch; material for artificial paving; saccharin, a substance three hundred times sweeter than sugar, and saccharin-amide, still sweeter; lampblack, material for red ink, lubricating oils, varnish, resin, almost our entire supply of ammonia, and hundreds of other things —all this science brings forth from this coal tar. By means of its products—this waste that surpassed its uselessness only by its offensiveness —we can make preserves without either fruit or sugar, perfumes without flowers, and coloring matter without animal or vegetable aid of any description.

What Science Does with the Ox.

Not many years ago when an ox was slaughtered forty per cent of the animal was wasted; at the present time "nothing is lost but its dying breath." As but one third of the weight of the animal consists of products that can be eaten the question of utilizing the waste is a serious one. The blood is used in refining sugar and in sizing paper, or manufactured into doorknobs and buttons. The hide goes to the tanner; horns and hoofs are transformed into combs and buttons; thigh bones, worth $80 per ton, are cut into handles for clothes brushes; foreleg bones sell for $30 per ton for collar buttons, parasol handles, and jewelry; the water in which bones are boiled is reduced to glue; the dust

from sawing the bones is food for cattle and poultry; the smallest bones are made into bone-black. Each foot yields a quarter of a pint of neat's-foot oil; the tail goes to the "soup," while the brush of hair at the end of the tail is sold to the mattress maker. The choicer parts of the fat make the basis of butterine; the intestines are used for sausage casings or bought by gold-beaters. The undigested food in the stomach, which formerly cost the packers of Chicago $30,000 a year to remove and destroy, is now made into paper. These are but a few of the products of abattoirs. All scraps unfit for any other use find welcome in the gluepot, or they do missionary work for farmers by acting as fertilizers.

Value and Uses of Cotton-seed Waste.

Cotton-seed waste, which a generation ago accumulated at the ginhouses, filled up the streams, rotted in the fields, and became an irritating nuisance, is now worth about $30,000,000 a year. Every bale of cotton leaves a legacy of half a ton of seed, which, it is said, brings the planter nearly as much as his cotton. The oil is used for finer grades of soap, as a substitute for lard, and is so near olive oil that an expert can hardly detect the difference. The hulls are fed to cattle, make an excellent fuel, are valuable as paper stock, and when burned the ashes

make a fertilizer which is most efficacious. It has recently been discovered that cotton-seed oil, with the addition of eighteen per cent of crude India rubber, makes an imitation which cannot be distinguished from genuine rubber.

Marble Chips and Corncobs.

Marble chips, formerly wasted or trodden down in public roads, are now mixed with cement, and made into marble mosaics for paper-weights, urns, cornices, mantels, and may even be made into building fronts, cemetery vaults, and tombstones.

Corncobs are made into pipes, or, dried and soaked in kerosene, they form excellent fire coaxers. Corn pith is used as a lining for war ships, and is packed in narrow slits abutting the steel packing. When a shell perforates a ship's side it tears a hole through the corn pith packing. The inrush of water saturates the pith, which enlarges enormously. It swells and quickly covers the breach, damming the flow, and perhaps saving a ship to the nation. This is an American idea, tested and approved by Chief Constructor Hichborn, of the Navy Department.

Paper Made from Anything with a Fiber.

Paper making has redeemed more articles of waste to a useful life than any other branch of human industry. Paper can be made of any-

thing that has a fiber. Over fifty kinds of bark are now used, while old sacking or bagging makes a good quality. It is also made from banana skins, bean stalks, pea vines, cocoanut fiber, clover, and timothy, hay, peat, straw, fresh-water weeds, seaweed, and more than a hundred different kinds of grass. Among the other materials that have been utilized as paper makers are hair, fur and wool, asbestos, hop plants, and any and every kind of grain—even leaves, husks, and stems of Indian corn. Nearly every kind of moss can be made into paper, as can also sawdust, shavings, thistles and thistledown, tobacco stalks, and tan bark.

Old Leather in New Forms.

The beautiful embossed leather paper, covering the walls of fine libraries, and the delicate stamped leather fire screens may, like many social upstarts, be ashamed of their ancestry. Investigation proves them to be really nothing but thick paper covered with a layer of pressed leather pulp, made by pulverizing the leather in old boots and worn-out shoes, captured by scavengers in their raids on the ash barrels of society. Old shoes, no matter how degraded and worn in the service of man, have a partial reincarnation. Pieces are taken from their uppers and soles to form parts of shoes for children; the smallest pieces are used to elevate

womankind by the high Louis XV heels. The steel nails leave the scraps at the suggestion of the attractive magnet, while the brass and copper nails, rescued later, pay the entire cost of the old shoes. The clippings and cuttings, transformed into a paste, reenter society as artificial leather, and the residue, even unto dust, is carefully gathered as a fertilizer for farming purposes.

Possibilities of Broken Glass.

The waste of glass furnaces is now made useful. Into a fire-resisting mold are placed fragments of glass of various colors, which are then raised to a high temperature. The coherent mass thus produced can be dressed and cut into beautiful mottled blocks and slabs, forming an artificial marble of decorative service. Designs in relief can be obtained by pressure while the material is still plastic. From broken colored glass a "stained glass" window can be made by firing, without the ordinary slow process of "leading." A prosaic soda water bottle, in the final fulfillment of its destiny, may dazzle the eyes as brilliant "diamonds" or other "precious stones" on the shirt fronts and fingers of wearers of cheap jewelry. These bottles are also used for chimney ornaments, inferior glass for manufacturing districts, and also for making emery powder glass paper. From one

to two thousand tons of cullet, or broken glass, are collected in the streets of London every year.

The Many Uses of Slag.

Slag, the refuse from smelting works, accumulates at the rate of millions of tons a year, its bulk being three times that of the iron from which it was separated. For centuries it has formed mountains near furnaces, it has been dumped recklessly into ravines and rivers, it has trespassed into valuable fields and towered high in its insolence. Archæologists, by these monuments of waste, have located the furnace fires of antiquity that smelted ores when the world was young. Slag, since it has reformed and become useful, has entered into the construction of roads, and has been made into bricks, paving blocks, tiles, and railway sleepers. In great monoliths, weighing over three tons each, it has formed breakwaters. It has proved its value as material for paint, because of the fifty-five to seventy-five per cent of pure oxide it contains. As mineral wool, resembling asbestos, it is an excellent nonconductor of heat, and is used by architects as a filling under Mansard roofs.

Wooden Floors Worth $67,000.

In handling so precious a metal as gold the waste problem assumes serious proportions. In

gold mining the "tailings," or refuse part of stamped ore, went into the waste heap. The new cyanide process searches this waste and forces it to surrender its treasure. This in South Africa alone is equal to nearly five million dollars a year. In jewelry manufacturing establishments every precaution is taken to guard against waste—even the water in which workmen wash their hands and the towels they use are saved and searched. When a large watch-case-making firm went out of business in New York a few years ago, though they had throughout used every safeguard against loss, they took up three floors of the building, and with all the accumulated rubbish reduced them to ashes. From the cremation they recovered sixty-seven thousand dollars' worth of gold. When a new roof was put on the Mint at Philadelphia it was suggested that invisible fumes might have conveyed golden plunder to the ceiling, so the leaden roof was melted, and surrendered eight hundred and twenty-seven dollars' worth of gold and silver. Putting down a grated floor in the Mint saved the sum of eighty thousand dollars.

Value of Woolen Mills' Waste.

The waste liquids from woolen mills threatened, like Tennyson's "brook," to "run on forever," till science came to the rescue. The

recovered product called "magma" is caught in canvas bags and subjected to hydraulic pressure. It yields an oil which, when distilled, is a combination of cloth oil (used in wool and jute spinning and in soap making) and stearin, from which candles are made. There is also a black refuse, valuable as a fertilizer; a hard pitch, unequaled as a lubricator in iron rolling mills; and a light spirit oil, used to dissolve rubber.

Seaweed Yields Food, Drink, and Medicine.

Kelp, or seaweed, usually considered one of nature's superfluities, if properly treated is a source of wealth. One ton of good kelp will produce eight pounds of iodine, large quantities of chloride of potassium, four to ten gallons of volatile oil, three or four gallons of naphtha, and one hundred and fifty to four hundred pounds of sulphate of ammonia. It may be used as food, drink, and medicine. When converted into gelose it is a vegetable isinglass. In France a gelatine or gum is made from it which is used in finishing cotton fabrics and in making artificial leather. Large crops of seaweed may be cultivated by placing large stones within tide mark on sandy shores.

XIV

Roentgen Rays

A translation of PROFESSOR ROENTGEN's original article, with explanatory notes, by CHARLES B. THWING, Ph.D., Professor of Physics in Knox College

INTRODUCTION.

IT seldom happens that the original announcement of a scientific discovery is read by anyone outside of a little circle of scientific men. It follows, therefore, that, when in January, 1896, the news of Roentgen's startling discovery was cabled across the Atlantic the general public hardly knew whether or not to believe the sensational statement that a way had been found to see and to photograph the bones of the hand and other heretofore invisible objects. Physicists, however, who had kept track of the work of Hertz and Lenard, at once saw that Roentgen's results were but the logical outcome of Lenard's work. Indeed, Lenard had made shadows of bits of metal on a fluorescent screen, and had fixed these shadows on a photographic plate more than a year before, but his results had not reached the stage where they could appeal to the popular imagination, and, as a consequence, the public heard nothing of them.

Professor Roentgen's report of his researches was made public at a meeting of local scientists

in the little university town of Würzburg, in December, 1895. It was written for scientists, yet the style of the article is so clear and the language so simple that it seemed best to translate the article almost literally, making only such changes as the different idioms of the two languages require. My purpose in following thus closely the author's own language is to give the young reader a glimpse of the great scientist himself. Note as you read the article—and it will well repay repeated reading—how it reveals the patient thoroughness of the scientist, who, after he has discovered a fact that will startle the world, does not rush into print with the announcement of his discovery, but shuts himself up in his laboratory and labors night and day for months to find out all he possibly can that will throw light upon the relations of his new facts to the great body of facts called science. Notice, too, how carefully guarded all his statements are, how fully he takes into account the work of others, and how utterly free the whole article is from any manifestation of the controversial spirit or any evident consciousness that the writer's work is especially worthy of public attention.

The metric measures are given together with their approximate English equivalents. If the reader will remember that 25.4 millimeters make

an inch, and that one thousand millimeters or one hundred centimeters make a meter he can easily reduce the measures for himself.

The illustrations were prepared for this article. The original article was not illustrated.

ON A NEW KIND OF RAYS.

BY W. C. ROENTGEN.

From the proceedings of the Würzburg Physico-Medical Society for 1895.

1. If the discharge from a large induction coil or similar apparatus is sent through a Hittorf's tube, a Lenard's tube (Fig. 3) with high vacuum, or a Crookes's tube while the tube is inclosed in a covering of black cardboard, a screen which has been coated with barium platinocyanide will, if held near the tube in a dark room, glow brilliantly every time the discharge passes. It makes no difference whether the side of the screen which was coated or the other side is toward the tube. The fluorescence is visible even at a distance of two meters (seven feet) from the tube. It is easy to satisfy oneself that the fluorescence has its source in the tube and nowhere else.

[In 1869 the German physicist, Plücker, engaged the instrument maker Geissler to make for him glass tubes, into the ends of which platinum wires were sealed, much as in the modern electric lamp, but at opposite ends of the tube. The tube was then exhausted of air by means of an air pump, and the electric spark was sent through the tube, the remaining

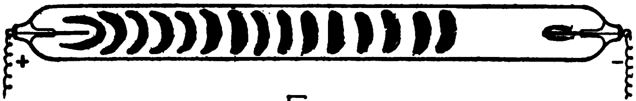


FIG. 1.

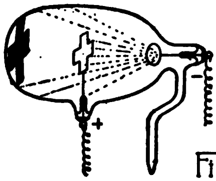


FIG. 2.

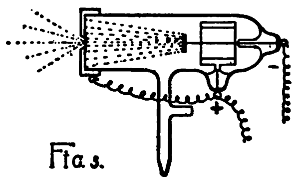


FIG. 3.

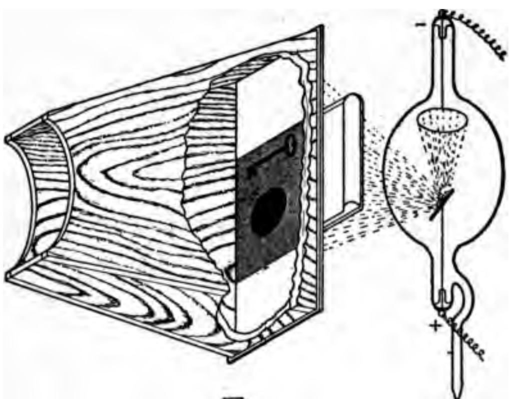


FIG. 4.

Fig. 1 shows a typical Geissler's tube; Fig. 2, a Crookes's tube; Fig. 3, a Lenard's tube; Fig. 4, an X ray tube and fluoroscope with shadow picture of a book containing a key and a coin.

gas in which glowed with beautiful colored light similar in appearance to the aurora borealis, which it was believed to explain.

Geissler afterward gave the tubes various beautiful forms and put them upon the market. They are now known by his name. (See Fig. 1.) In these tubes only about one thousandth part of the air remains.

Hittorf carried the exhaustion of the tube farther and observed the so-called cathode rays which were studied thoroughly by Crookes, an English physicist, who supposed the rays emanating from the cathode to consist of particles of gas which, in the almost complete vacuum which he obtained, moved without colliding with each other. (See Fig. 2.) He called this rarefied gas by the name of radiant matter.]

2. The first notable feature of this phenomenon is the fact that there is an agent which is able to penetrate black cardboard, a substance which neither the visible nor the ultraviolet rays of the sun or of the arc light are able to penetrate, and to excite powerful fluorescence. We are at once led to investigate whether other substances besides the cardboard behave in the same manner.

We find, on experiment, that all bodies are thus transparent, but in very different degrees, as the following examples will show. Paper is exceedingly transparent. The fluorescent screen lighted up plainly through a book of one thousand pages (Fig. 4). The printer's ink offered no perceptible hindrance. Fluorescence was plainly visible through two packs of playing

cards, while a single card between the tube and screen produced almost no effect whatever. A single thickness of tinfoil was hardly perceptible, but a number of thicknesses gave a noticeable shadow upon the screen. Thick blocks of wood are transparent. Pine boards an inch thick absorb the rays but slightly. A sheet of aluminum 15 millimeters (.6 inch) thick weakened the effect very noticeably, but was not sufficient to make the fluorescence disappear entirely. Sheets of hard rubber several centimeters thick (2.5 centimeters, one inch) allowed the rays to pass. Glass plates of the same thickness acted very differently, depending upon whether the glass contained lead or not. That containing lead (flint glass) is much less transparent than other sorts.

If one holds the hand between the tube and the screen one sees dark shadows of the bones in the very faint shadow picture of the hand. (See page 237.)

Water, carbon disulphide, and other liquids of different sorts, when examined in vessels of mica, proved to be very transparent. I was not able to find that hydrogen is more transparent than air. Behind plates of copper, silver, lead, gold, platinum, the fluorescence is visible, provided that the plates are thin enough. Platinum plates .2 millimeter (.008 inch) thick are still

Shadow picture of human hand, from a photograph. It shows the structure of the bones distinctly. Notice the layers of flesh between the thumb and forefinger. The sesamoid bone of the thumb is shown also. Such pictures are commonly called "radiographs." The word is half Greek and half Latin. A better word is "sciagraph." This is from two Greek words meaning shadow record.

transparent. The silver and copper plates may be yet thicker. Lead plates 1.5 millimeters (.06 inch) are as good as opaque, and are therefore frequently used for screening off the rays. A wooden rod three fourths of an inch square, one side of which was painted with lead paint, was transparent when held with the painted edge parallel to the direction of the rays, but when held so that the rays must pass through the painted side it cast a dark shadow. The salts of the metals, either solid or in solution, fall into a series exactly corresponding to the metals themselves when examined with reference to their relative transparency.

3. The above-mentioned results, as well as others, point to the conclusion that the relative transparency of different substances when examined in plates of the same thickness is determined essentially by their density. At any rate no other property is so evidently effective as is this. That density is not the sole factor is, however, evident from the following experiment: I examined plates of about the same thickness of glass, aluminum, calcite, and quartz. These substances have almost equal densities, and yet it was very evident that the calcite was noticeably less transparent than the other substances. I have not noticed that calcite is especially fluorescent.

4. With increasing thickness all bodies become less transparent. In order to see if I might perchance find a relation between thickness and transparency, I took a number of photographs with different parts of the plate covered by a different number of layers of tinfoil. I shall make photometric measurements of these as soon as I have a suitable photometer, or light measure.

5. Sheets of platinum, lead, zinc, and aluminum were made of such thicknesses that all were about equally transparent. The following table shows the thickness in millimeters, the relative thickness as compared to platinum, and the density:

	Thickness.	Relative Thickness.	Density.
Platinum	.018	1	21.5
Lead	.05	3	11.3
Zinc	.1	6	7.1
Aluminum	3.5	200	2.6

It is evident from these values that it is by no means true that like transparency is found for different metals when the products of their density and thickness are the same. The transparency increases much faster than this product decreases.

6. The fluorescence of barium platino-cyanide is not the only noticeable effect of the X rays. Many other substances fluoresce, as, for ex-

ample, the phosphorescent calcium compounds, uranium glass, common glass, calcite (Iceland spar), rock salt, etc.

Of especial importance is the fact that photographic dry plates have proved to be sensitive to the rays. We are therefore able to keep a permanent record of many phenomena, thus excluding mistakes of the sort known as optical illusions. I have photographed in this way many of the more important observations which I have made with the fluorescent screen. The almost perfect transparency of paper makes it very easy to inclose the plate in an envelope, or in an ordinary plateholder, when the exposure may be made in broad daylight. It is necessary to be careful not to leave undeveloped plates near the apparatus, since they would soon be fogged, even when inclosed in the usual light-tight boxes.

It is as yet a question whether the chemical effect is produced upon the silver salts by the X rays directly or by fluorescence in the glass or in the gelatine itself. Films may be used as well as glass plates.

I have as yet no experimental proof that the X rays generate heat. It seems likely that they do, however, since fluorescence is a proof that the energy of the rays may be transformed. It is certain also that not all of the

X rays which fall upon a body leave the body as X rays.

7. When I had found that the X rays were affected in their passage through different bodies by the density of the bodies, I made haste to try the effect of a prism, to see if they would be refracted. Experiments made with hollow prisms of mica, having an angle of thirty degrees, and filled with water or with carbon disulphide, showed no deviation whatever, either on the fluorescent screen or on the photographic plate. By way of comparison I passed light rays through the prism and found them to be deflected ten millimeters and twenty millimeters respectively by the two liquids. With prisms of hard rubber and aluminum I obtained pictures on the photographic plate which seemed to show a slight deviation. The fact is, however, very uncertain, and if there is any deviation it is exceedingly small, corresponding to an index of refraction of not more than 1.05. Moreover, I was able to obtain with the fluorescent screen no evidence of deviation whatever.

Considering this unsettled state of the case, and the great importance of the question whether X rays are or are not deviated in passing from one medium to another, it is desirable to attack the question from another side. A layer of pulverized substance does not allow light to pass

as freely as does the same thickness of the substance in a solid sheet, because of the irregular refraction and reflection of the light by the small particles. In the case of the X rays no such scattering is observable. The experiment was tried with finely pulverized salt, with fine electrolytic silver, and with zinc dust. In every case there was no apparent difference, whether the powder or the solid substance was used.

It follows as a matter of course that if the rays are not refracted they cannot be focused by a lens. Lenses of rubber and of glass proved to be utterly useless. The shadow picture of a rod is darker in the middle than at the edges. The shadow of a glass tube filled with a substance more transparent than glass (as air) is darker at the edges than in the middle.

[That terminal or wire by which the electric current enters a vacuum tube is called the anode; that by which it leaves, the cathode; from two Greek words meaning "the way in" and "the way out."

Lenard's tube (Fig. 3) will be referred to in another note. The X ray tube (Fig. 4), as now made, is a slightly modified form of Crookes's tube. Roentgen's experiments were repeated by means of Crookes's tubes in physical laboratories everywhere as soon as his discovery was announced.

Crookes placed diamonds and other minerals in his tubes, and they fluoresced brilliantly. The glass of the tube also exhibited a beautiful green fluorescence opposite the cathode. Crookes and many others thus worked for days surrounded by

the invisible rays without once suspecting that these rays were passing through their very bodies.

The "fluoroscope" (Fig. 4), as now used, consists of such a fluorescent cardboard screen as Roentgen used mounted at the end of a dark box, the other end of which is held before the face, thus permitting the shadow pictures to be seen without darkening the room.

The index of refraction of a substance as compared to air is a number expressing the amount that the ray, of light, for example, will be bent in passing at an angle from air into that substance. It is equal to the velocity of the ray in air, divided by its velocity in the other medium. Thus light travels but three fourths as fast in water as in air. The index of refraction of water is therefore $4 \div 3$, or 1.33. The index of refraction of glass for light is about 1.6.]

8. As far as the experiments already described are concerned the question of any regular reflection of rays would seem to be settled in the negative. Some additional experiments which point in the same direction I shall pass over here.

One experiment, however, seems at first glance to point to an opposite conclusion. I placed upon the back of a photographic plate bits of polished platinum, lead, zinc, and aluminum plate, cut in the form of stars. The plate was wrapped in black paper and exposed to the rays. When developed the portions of the plate under the platinum and lead, and especially under the zinc plates, were noticeably darker than the portions of the plate not so

covered. The aluminum had no effect whatever. It would seem, therefore, that the three metals mentioned reflect the rays. Still, the effect might be due to other causes; so, to make the matter sure, I tried the experiment again, with a thin sheet of aluminum between the plate and the bits of metal. The aluminum is opaque to ultraviolet light, but very transparent for X rays. The result was exactly the same as before; so I consider that reflection of the X rays by the metals mentioned is proved.

Since the X rays are not refracted in passing from one medium to another we must conclude that they travel with the same velocity in all bodies, and that they really travel in a medium which is present everywhere and in which the particles of bodies are imbedded. The particles of bodies hinder the passage of the rays in proportion, generally speaking, to the density of the body through which the rays pass. (See Fig. 4.)

9. It might be possible, therefore, that the arrangement of the molecules in any body might have some influence upon the transparency of that body for the rays. A piece of Iceland spar, for example, might show different degrees of transparency depending upon whether the rays passed parallel to the axis of the crystal or at right angles to it. Experiments with Iceland

spar and with quartz gave no decisive answer to the question.

[Light has different velocities in Iceland spar according to whether it travels parallel to the axis or at right angles to it. It has, therefore, different indices of refraction in the two cases, and Iceland spar is therefore known as a doubly refracting medium. Any object seen through a crystal of Iceland spar appears double.]

10. It is well known that Lenard in his beautiful researches with cathode rays proved that these rays, which he examined after passing them through thin sheets of aluminum, are phenomena of the ether, and that they are diffused when they enter any body. Something of the same sort may be said of our rays.

In his last work Lenard determined the absorptive power of different substances for the cathode rays. He found it to be proportional to the density of the gas in the tube. For the X rays I found the intensity of the light on my screen to be inversely proportional to the distance of the screen from the tube. It follows that the air absorbs a much smaller fraction of the X rays than of the cathode rays. This agrees with the fact before stated that the rays affect the screen even at a distance of two meters. Other bodies behave in like manner; they are more transparent to X rays than to cathode rays.

[Hertz, the great German physicist, who, by his famous experiments with electrical waves, demonstrated that light is a form of electrical radiation, showed by experiment that the cathode rays are able to penetrate thin sheets of metal if they are placed inside the tube. He suggested to his assistant, Lenard, that it was quite likely that the same thing would happen with the metal outside the tube. Lenard experimented with tubes (see Fig. 3) having an aluminum window, through which the rays passed freely into the open air, or at times into a partial vacuum. While a student under Hertz and Lenard at Bonn in 1893–94 I had the good fortune to follow the progress of Lenard in his investigations. He showed me at that time shadow pictures of various objects and photographs showing the different transparency of various substances for the cathode rays.

The published work of Lenard attracted the notice of Roentgen, who pursued the subject with the results so well known to the world. The Royal Society of England recognized the claim of both physicists to equal honor by awarding the Rumford medal to both men, "for discoveries in the properties of electrical discharges." Roentgen was knighted by the Bavarian government, and Lenard has been appointed Professor of Physics at Heidelberg. The latter was no empty honor for a man who had been, during the years of his patient investigations, acting as university tutor at a salary of $300 a year, and boarding himself to keep soul and body together.]

11. Another very noticeable difference between the cathode rays and the X rays is that while the cathode rays are easily deflected by a magnet, I have not been able, even with the most powerful magnetic field, to obtain any deflection of the X rays whatever.

This property of the cathode rays has served

hitherto as a marked characteristic of those rays. It must be remembered, however, that both Hertz and Lenard distinguished three kinds of cathode rays, which were characterized respectively by (1) the power to produce phosphorescence, (2) the property of being absorbed or diffused, (3) the ability to be deflected by a magnet. Yet they found a noticeable deflection for all of the rays examined by them, and I do not believe that this characteristic will be abandoned except on the strongest grounds.

12. After a large number of experiments directed to the question of the location of the point in the tube from which the X rays radiate it was definitely settled that the walls of the tube are the source of radiation. In fact the X rays have their source exactly at those points in the tube where, according to the statements of other investigators, the cathode rays strike the walls of the tube. If we cause the cathode rays to be deflected by means of a magnet so that they strike the walls of the tube in a new place, that place at once becomes the source of X rays.

On this account it is not possible to consider that the X rays, which cannot be deflected by a magnet, are simply cathode rays which have been refracted or reflected.

I come to the conclusion, therefore, that the

X rays are not identical with the cathode rays, but that they are generated by the cathode rays in the walls of the tube.

13. This occurs not only in glass, but in aluminum also, as I have proved by experiment. Other substances will be examined later.

14. My justification for calling the agent which proceeds from the walls of the tube by the name "rays" is in the fact that it casts perfectly regular shadow pictures upon the fluorescent screen and the photographic plate. Many of these shadow pictures, the production of which has a remarkable charm for one, I have observed, and from time to time have photographed also. I possess, for example, the shadow of the profile of the door which separated the rooms which contained the tube and the photographic plate; pictures of the bones of the hand; of a spool of copper wire; of a set of metal weights inclosed in a wooden box; of a piece of metal showing a lack of homogeneity of structure, etc.

The rectilinear propagation of the waves is shown also by the fact that I was able to make a pinhole picture of the apparatus itself while it was inclosed in black paper. The picture is faint, but unmistakably correct.

15. I have sought much to find any interference phenomena with the rays, but unfortu-

nately without result; perhaps because they are not intense enough.

16. Experiments to show whether electrostatic forces are in any way influenced by the rays I have begun, but have not yet finished.

[Both Lenard and Roentgen have pushed their investigations farther, and thousands of articles have been published by other investigators since 1895, but I think it would be a fair estimate to say that these two patient, thorough Germans have found out more about these wonderful rays than all the rest of the world together.]

17. If now we ask what the X rays (which cannot be cathode rays) really are we shall at first think of ultraviolet light, which, like them, produces powerful fluorescent and chemical effects. But here we encounter serious contradictions; for if the X rays are ultraviolet light, then ultraviolet light must possess the following properties:

(a) It must pass from air to water, carbon disulphide, aluminum, rock salt, glass, zinc, etc., without suffering any perceptible refraction;

(b) It must not be, to any noticeable extent, regularly reflected by those substances;

(c) It cannot be polarized by any means yet employed;

(d) Its absorption is influenced by no other property of the body so much as by its density.

That is to say, we must assume that this

ultraviolet light behaves in a totally different manner from any rays, either ultrared, invisible, or ultraviolet hitherto known.

To this conclusion I have not been able to bring myself, so I have sought for another explanation.

There does seem to be a sort of relationship between the new rays and light rays. At any rate the shadow pictures, the fluorescence, and the chemical action, which are common to both kinds of rays, point to such a connection.

Now, it has long been known that besides the transverse vibrations in ether, of which light is known to consist, it is possible for longitudinal vibrations to be present also. Indeed, according to the views of many physicists, such vibrations must be present. To be sure their existence has not yet been proved, and consequently their properties are not yet known. Might not the new rays be attributed to such longitudinal vibrations in the ether?

I must confess that as my investigations have progressed I have found this suggestion growing upon me, and I have therefore ventured to offer the conjecture here, though I am very well aware that this explanation requires a much broader foundation than it yet possesses.

The Physical Institute of the University,
Würzburg, December, 1895.